Essays on Fiscal Policy and Public Debt Sustainability

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Contents

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List of Abbreviations

BIS Bank of International Settlements. 76, 77

CDS Credit Default Swaps. 75, 77, 85, 88, 96, 99, 100, 109

COVID-19 coronavirus pandemic. 15

DSGE dynamic stochastic general equilibrium. 74

EO Economic Outlook. 71, 75, 76

GDP Gross Domestic Product. 6, 13–15, 38, 71, 75, 76, 82, 85, 86, 90, 111

GNI Gross National Income. 20, 21, 32, 34, 36, 38

IMF International Monetary Fund. 14

OBR Office for Budget Responsibility. 15, 16, 20, 21, 34, 38, 106

OECD The Organisation for Economic Co-operation and Development. 32, 70, 71, 73, 75–77, 80, 99, 109, 110

ONS Office for National Statistics. 16, 32, 34

QNA quarterly national accounts. 76

STVAR smooth transition vector autoregressive. 80

TFP total factor productivity. 23, 53

Abstract

This thesis studies two topics of fiscal policies and public debt sustainability. In Chapter 2, the study is motivated by the fact that UK government debt relative to output has increased dramatically in the last decade. In addition, an aging population in recent years presents many challenges to government expenditures. Consequently, the UK is projected to experience further upward pressures on government debt. This chapter uses a Neoclassical Growth Model to explore the amount of additional tax revenues needed to finance the future government expenditures and at the same time reduce the debt to output ratio to 60%. We find that the required revenue to achieve fiscal stability is in the range of 20-24% of consumption expenditures. Also, when a distorting tax (consumption tax or labor income tax) is used to achieve the goal, such tax rate needs to increase to a very high level, even though the government has broadened its tax base.

Chapter 3 aims to identify the public investment shock for a sample of 14 OECD countries from 1985 to 2018 and investigate how public debt sustainability affects the macroeconomic effect of a public investment shock. This study identifies public investment shock as forecast errors of public investment and uses the local projection method to estimate the responses of a set of key macroeconomic variables to public investment shocks. The empirical result shows that the public investment shocks can increase the output, with a multiplier of 2.3 on average over three years. Moreover, public debt sustainability affects the effectiveness of the public investment: The responses of output are statistical significant larger in a weak-debt regime (i.e., the debt-to-GDP ratio is greater than a specific high level) than in a strong-debt regime (i.e., the debt ratio is less than a specific low level). To investigate the channels through which public debt sustainability can affect the effectiveness of public investment shocks, we also consider the response of other macroeconomic variables and find that public debt sustainability can limit the effectiveness of public investment through private consumption and borrowing costs.

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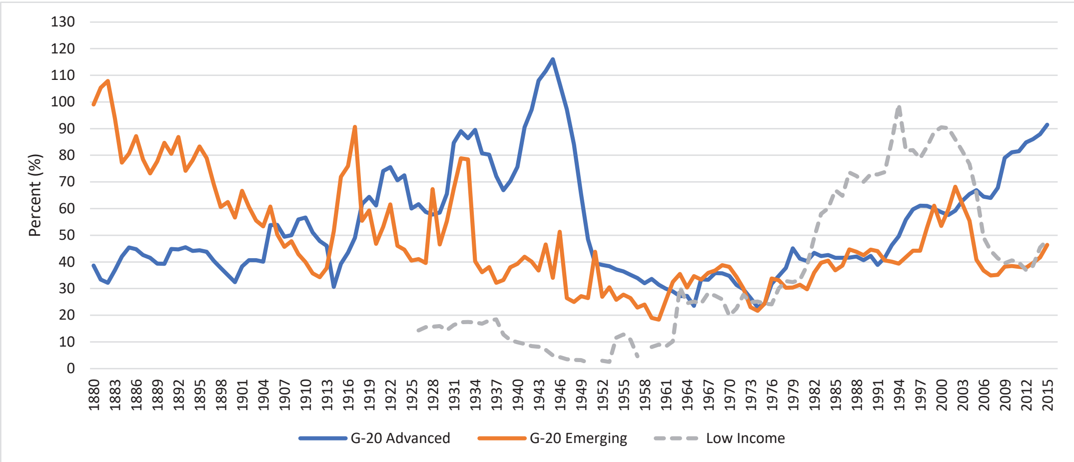
Chapter 1

Introduction

The expansionary fiscal policy involves the government seeking to recover the economy by stimulating the aggregate demand through tax cuts or increased government expenditure. Although many scholars had been skeptical of the effectiveness of the fiscal policy, especially since 1970s stagflation, the ability of fiscal policy to bring the economy out of the recession has been back in the spotlight due to the substantial fiscal stimulus packages launched in many countries (e.g., China, European countries, and the United States) to combat the global financial crisis of 2007. The recession appeared to be overcome until 2010, when production in certain economies returned to pre-crisis levels. The crisis, however, evolved into a public debt crisis as a result of governments' bailing out private financial institutions, resulting in a dramatic increase in the level of public debt. Additionally, the increase in public debt exceeded the growth rate of GDP, especially in some developed countries, resulting in an increase in debt-to-GDP ratios. Figure 1.1 plots the historical public debt-to-GDP ratios for various country groups. It shows that the debt ratios across G-20 advanced countries were about 30% higher, on average, in 2015 than in 2007.[1] In fact, the high level of debt accumulation started in the mid-1970s when central banks implemented the tightened monetary policy in most developed countries to curb excessive inflation rates. The real interest rates spike with

[1] G-20 emerging countries and low-income countries exhibited lower debt-to-GDP ratios in the post-crisis period.

relatively slow growth in real GDP resulting in the debt-to-GDP ratios growing considerably fast in advanced economies, from 24% in 1975 to 64% in 2007.[2]



Source: Historical public debt database, International Monetary Fund (IMF).

Figure 1.1: Public debt-to-GDP ratios across country groups, 1880-2015 (Group PPP GDP-weighted average, in percent of GDP)

1.1 Public debt dynamics

This section briefly presents a simple framework that determines the debt dynamics, followed by Escolano (2010). The following framework assumes that the government must borrow and issue new debt to finance the primary deficit. Thus the total debt stock at the end of period t (B_t) can be expressed using the following equation:

$$B_t = B^d_{t-1}(1 + i^d_t) + B^f_{t-1}(1 + i^f_t)(1 + e_t) - P_t + O_t \tag{1.1}$$

where B^d_{t-1} and B^f_{t-1} denote the domestic and foreign-currency debt stock at time $t-1$, separately; i^d_t and i^f_t stand for interest rates on domestic debt and foreign-currency debt, separately; P is the primary balance which is defined as the difference between government revenues and expenditures excluding public debt interest payments; and O

[2]The debt-stabilizing primary surplus equals the automatic debt dynamics, which depends on the real interest rate and the real GDP growth rate. An increase in the real interest rate and a reduction in the real GDP growth rate requires a higher level of the debt-stabilizing primary surplus. Debt accumulation occurs when the fiscal policies are not able to meet the required debt-stabilizing primary surplus.

denotes any other debt-creating flow adjustments. Equation 1.1 indicates that the total debt stock at the end of time period t is equal to the sum of domestic debt stock and the foreign-currency debt stock at time $t-1$, their interest expenses paid at time t, and other debt flows, subtracting the primary balance at time t.

Equation 1.1 can be used to capture the dynamics of the debt-to-GDP ratio by dividing both sides by real GDP:

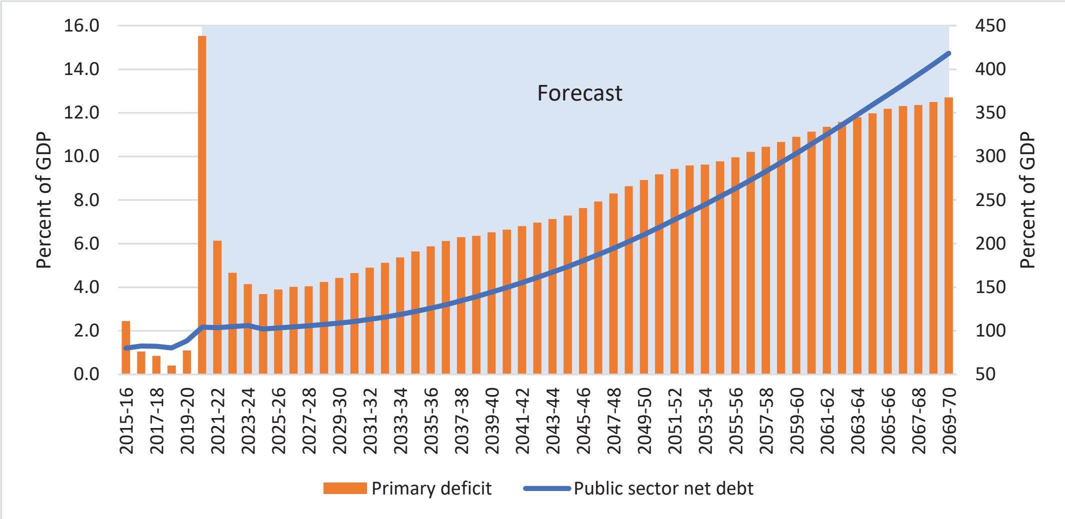
$$b_t = \frac{b_{t-1}^d (1+r_t^d)}{1+g_t} + \frac{b_{t-1}^f (1+r_t^f)(1+\varepsilon_t)}{1+g_t} - p_t + o_t \tag{1.2}$$

where lowercase letters b and p denote the debt stock and primary balance as a ratio to real GDP; r stands for the real interest rate; ε indicates the real exchange rate depreciation; the real GDP growth rate is denoted as g; and o can be treated as the residual which captures other identified flows as a share of GDP. Equation 1.2 can be rearranged by deducting past debt from both sides to illustrate the dynamic change in debt ratios:

$$b_t - b_{t-1} = \frac{r_t^d b_{t-1}^d + r_t^f b_{t-1}^f - g_t b_{t-1}}{1+g_t} + \frac{b_{t-1}^f (1+r_t^f)\varepsilon_t}{1+g_t} - p_t + o_t \tag{1.3}$$

Equation 1.3 implies that critical variables affecting public debt sustainability include outstanding debt, interest rate, exchange rate, growth, and primary balance. Among these factors, primary balance is critical for short-run sustainability because it demonstrates the extent to which a government can meet its obligations without acquiring extra debt.

Figure 1.2 shows the UK's government primary deficit (non-interest government expenditure minus government revenue) and public sector net debt as a share of GDP, and the projection for each of them. Office for Budget Responsibility (OBR) predicts that the UK's primary deficit and the debt-to-GDP ratio will increase dramatically in 2020-21 as a result of the coronavirus pandemic (COVID-19). Although the primary deficit ratio to GDP is projected to drop after that, it is still higher than the pre-virus period and soon increases steadily in the long term. One stylized fact that can explain the trend is the population aging, which will raise the expense of pensions, health, and social care. As a result, the government's primary deficit will move from 0.4% of GDP in 2018-19 to 12.7% of GDP by 2069-70. The increase in the primary deficit, in turn, puts upward pressure on the public finances, and the public sector net debt will rise to an unprecedented high level in the next 50 years. The question is how fiscal policies should respond to future increases in public debt in order to bring it down to a manageable level.



Source: Office for National Statistics (ONS), OBR.
Note: Primary deficit (left-hand scale); Debt-to-GDP ratio (right-hand scale).

Figure 1.2: Central projection of the primary deficit and debt-to-GDP ratio

Chapter 2 uses a Neoclassical Growth Model to explore the amount of additional tax revenues needed to finance the future government expenditures and at the same time reduce the debt to output ratio to 60%. We find that the required revenue to achieve fiscal stability is in the range of 20-24% of consumption expenditures. Also, when a distorting tax (consumption tax or labor income tax) is used to achieve the goal, such tax rate needs to increase to a very high level, even though the government can broaden its tax base.

1.2 Public debt thresholds

Public debt is a double-edged sword. At moderate levels, it promotes economic growth by providing funds to finance government expenditures. With the help of public debts, governments would be able to increase production, improve the welfare and the living standard of citizens, control natural calamities, and implement infrastructure projects.

Nevertheless, history has taught us that an economy can become vulnerable as a result of excessive borrowing. When the debt-to-GDP ratio surpasses a certain threshold, the effect turns to be opposite (Reinhart et al., 2009). Using an extensive data set covering over 200 years and 44 countries, Reinhart and Rogoff (2010) discover that government debt levels of more than 90% of GDP are significantly associated with lower GDP growth. In line with these findings, Cecchetti et al. (2011) examine government, non-financial corporate, and household debt for 18 OECD countries and report that at moderate levels, debt improves welfare, while government debt levels above 80% to 100% of GDP, corporate debt above 90% of GDP and household debt above 85% of GDP, have a deleterious impact on growth. Checherita and Rother (2012) find a similar level of 90-100% for a panel of 12 euro area countries beyond which a rising debt-to-GDP ratio is related to a negative effect on long-run growth. By studying the case of developing countries, Yolcu Karadam et al. (2018) found the debt threshold in the sample of developing economies is at 88.2%.

While the impact of public debt on economic growth has been widely examined, the effect of public debt on the effectiveness of fiscal policies, particularly public investment, remains an unresolved and intriguing area of macroeconomics literature. In theory, the public debt can affect the response of output to a public investment shock via two channels: The first is known as Ricardian Equivalence. That is, at a high level of debt, an increase in public investment may decrease private consumption, as households with anticipation of tax rising in the future are willing to save more. The second channel is related to borrowing costs, as higher public debt tends to be associated with higher risk premiums and thus higher borrowing costs of the whole economy. As a result, the effectiveness of public investment on stimulating aggregate demand is undermined, or even turns to be opposite (i.e., crowding out effects) (Laubach, 2009; Lian et al., 2020).

Chapter 3 aims to identify the public investment shock for a sample of 14 OECD countries from 1985 to 2018 and investigate how public debt sustainability affects the macroeconomic effect of a public investment shock. This study identifies public investment shock as forecast errors of public investment and uses the local projection method to estimate the responses of a set of key macroeconomic variables to public investment shocks. The empirical result shows that public debt sustainability affects the effectiveness of the public investment: The responses of output is statistically significantly larger in a weak-debt regime (i.e., the debt-to-GDP ratio is greater than a specific high level) than in a strong-debt regime (i.e., the debt ratio is less than a specific low level). To investigate the channels through which public debt sustainability can affect the effectiveness of public investment shocks, we also consider the responses of other macroeconomic variables and find that public debt sustainability can limit the effect of public investment shocks through the private consumption and costs of borrowing.

The rest of the thesis is organized as follows. Chapter 2 investigates the tax policy reform in the UK in order to meet the future increases in government spending and reduce the debt to a sustainable level. Chapter 3 studies how public debt impacts the effectiveness of public investment. Chapter 4 summarizes the main findings and discusses future research.

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Chapter 2

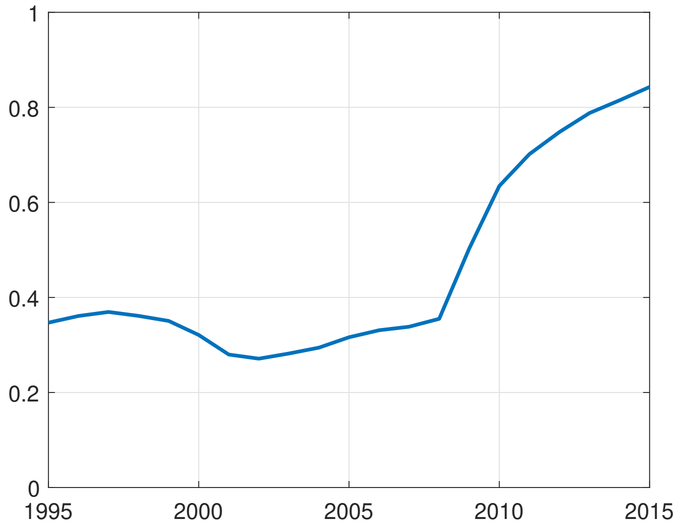
Government Debt and Fiscal Reform in the UK

2.1 Introduction

The UK government is facing significant fiscal pressure, which is reflected by a dramatic rise in government debt compared to the size of the economy. Figure 2.1 shows that the UK government net debt to Gross National Income (GNI) ratio has increased from 35% in 1995 to 84% in 2015.[1]

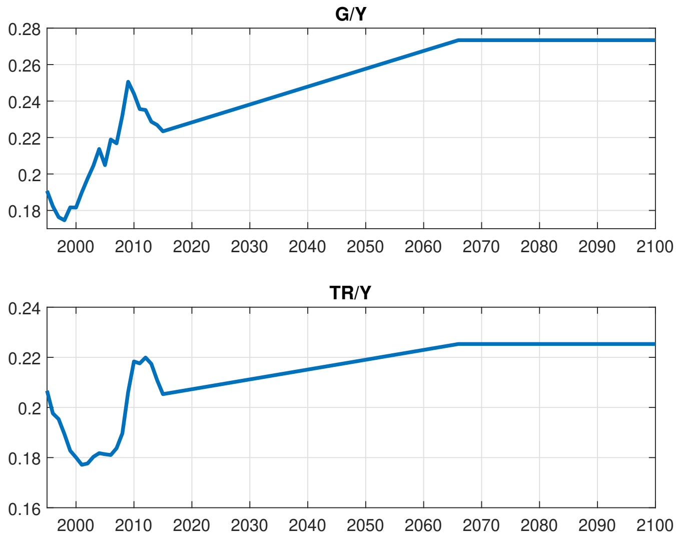
In addition, in the next few decades, the UK's public finances will receive more fiscal challenges from the effects of an aging population and additional non-demographic cost pressures (e.g., technological advances and the rise of chronic health conditions) on health spending. In order to maintain the social benefits at the current level, the UK government has to increase its spending as a share of national income on related items such as public pensions and the costs of health and long-term social care. According to OBR's forecasts, the ratio of government purchases to output is projected to increase from 22% in 2016 to 27% in 2066, and the transfer payments are projected to rise from 21% to 23% of GNI between 2016 and 2066 (OBR, 2017). The UK's government expenditures to output ratios are shown in Figure 2.2.

[1] Government net debt is defined as the difference between financial liabilities and assets of the public sector (excluding public sector banks).



Source: ONS: 1995-2015.

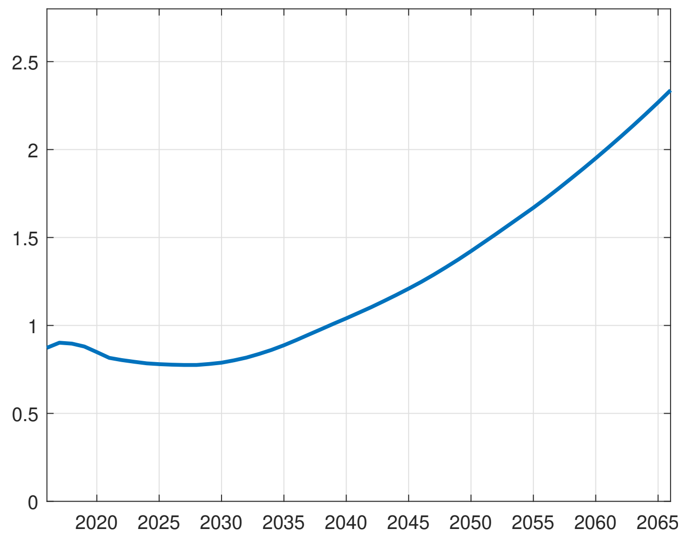
Figure 2.1: UK net debt to GNI ratio



Source: ONS: 1995-2015; Projections: 2016-2066.

Figure 2.2: UK government expenditures to GNI ratios

Obviously, without increasing tax revenue or cutting government spending, the budget deficits will grow over time, leading the debt to output ratio to continue to rise. Figure 2.3 shows the OBR's projection of public sector net debt as a share of GNI. While there is no explicit limitation on the growth of the debt to GNI ratio, it is reasonable to expect that it cannot rise to an unprecedented level. The UK government,



Source: OBR: 2016-2066.

Figure 2.3: Projections of UK public sector net debt to output ratio

therefore, needs to stabilize its debt at some point.

This research intends to provide different ways for the UK government to finance the increases in government spending and at the same time reduce the debt to output ratio to a specified level (i.e., 60%). In our benchmark experiment, the government is allowed to levy a lump-sum tax, which is equivalent to reducing the transfer payment in our model to reduce the fiscal deficit and restore fiscal stability. By doing this, we can explore the amount of revenue the UK government needs to pay for the projected increase in government expenditures and stabilize the debt. We will also attempt to explore if using a distorting tax (labor income tax or consumption tax) instead of a lump-sum tax is feasible to achieve our goal.

Numerous works have examined the fiscal reform associated with growing government debt in advanced economies. Several attempts have been made using the Overlapping Generations Model (OLG) to quantify the fiscal cost of an ageing population. For example, Kudrna et al. (2015) investigate the fiscal policy options to mitigate fiscal pressure arising from the aging of the Australian population. They conclude that to balance the budget in 2050, either non-age-related government spending must be reduced by 32% or the consumption tax rate must be increased by 28%. Nishiyama (2015) examines aging and fiscal reforms in the United States. They find that the demographically related fiscal gap is 2.92% of GDP. Two fiscal reforms are considered to close the fiscal gap in this paper: tax hikes and cutting transfer payments. Their results indicate that current generations prefer increasing marginal income tax to cutting transfer benefits, at the expense of future generations. With a large government debt and severe population aging, Japan's fiscal reform has risen to the forefront of scholarly concern. For example, Doi et al. (2011) evaluate the tax revenue required to finance the government spending and sustain the debt at 2010 level. Their results show that to achieve the goal, the tax revenue as a share of GDP is required to increase to 40- 47%. Braun and Joines (2015) investigate the fiscal costs of population aging in Japan using a general equilibrium model with a rich demographic structure. They project that a sovereign debt crisis would break out by 2039 if the Japanese government does not take any action to reduce the fiscal deficit, and at that point the fiscal consolidation requires the consumption tax rate to increase to over 50%. In contrast, if the consumption tax rate could be permanently increased to 36% in 2019, the intertemporal budget constraint could be satisfied.

To provide insights for fiscal policy in the short term, some of the other studies use the Neoclassical Growth Model with an infinitely lived representative household to explore the fiscal policies that could stabilize the government debt in Japan. This framework is developed by Hayashi and Prescott (2002), who explore the real reason behind the Japanese lost decade of growth. The Neoclassical Growth Model is the workhorse macro model. It is beneficial to explain how economies evolve dynamically in response to shocks and policies. It also generates model simulations that match actual data reasonably well. The examples using this model include Imrohoroglu and Sudo (2011a), who measure the impact of increasing the consumption tax rate to 15% combined with a growth rate of 3% in output over the next 20 years and have found that this cannot lead to a persistent primary surplus. Imrohoroglu and Sudo (2011b) examine the effect of economic growth on government debt in Japan, and the main finding is that in order to eliminate the debt, the total factor productivity (TFP) in Japan needs to grow at an unprecedentedly high rate of 6% per year for a decade. Hansen and Imrohoroglu (2016) study the fiscal reform and debt in Japan and have found that the required revenue to finance the projected increase in government spending is very high, which is 30 to 40 percent of consumption expenditure. When they use a distorting tax to finance future government expenditure, it also requires the tax to rise to over 60%.

We contribute directly to the literature by analyzing the fiscal reforms and government debt in the United Kingdom. Much of the existing literature pays particular attention to the empirical examination of whether the public debt is sustainable or not in the UK (Raybaudi et al., 2004; Dulger and Ozdemir, 2005; Holmes, 2006; Considine and Gallagher, 2008). However, they have not explored the fiscal adjustments that could be used to deal with the large primary deficits and government debt in the future. Botman and Honjo (2006), on the other hand, examine the macroeconomic effects of different fiscal adjustments by calibrating the IMF's Global Fiscal Model to the UK economy. To close the financing gap by FY2009/10 and stabilise the debt-to-GDP ratio at 45% from FY2009/10 onwards, they conclude that labour income tax rates need to be raised by approximately 2 percentage points under a delayed consolidation, whereas an early consolidation beginning in FY2006/07 can stabilise the debt-to-GDP ratio at 37%. Increases in labor income taxes are more beneficial in the long run than rises in corporate income taxes. Also, benefits are greater when the adjustments are implemented through government transfers or spending cuts than through tax hikes. This paper, however, does not consider the effect of the consumption tax. In addition, the model in this study is calibrated to the UK economy using the actual time series for 1997-2005. In fact, the debt to output in the UK has increased dramatically since 2008 (see Figure 2.1) and it is projected to increase further. Therefore, it is necessary to explore the fiscal reforms by considering much higher levels of debt-to-GDP ratios. Our research contributes to the existing literature by investigating the tax revenue, consumption tax rate, or labor income tax rate required to finance the future increased government expenditure and at the same time reduce the debt to output ratio and sustain it at the level of 60%. Our findings show that the tax revenue required as a share of consumption expenditures is in the range of 20%-24%. Compared the results with those of Hansen and Imrohoroglu (2016), one could find that due to the lower fiscal burden, the revenue required to pay for the increased government expenditure and stabilize the debt to output ratio in the UK is less than that in Japan. Nevertheless, to finance future expenditures, the consumption tax rate or labour income tax rate must climb to an unprecedentedly high level. In particular, to reduce the debt to output ratio from 200% to 60%, the labor income tax needs to increase by around 5 percentage points, while the consumption tax rate is required to be raised by 3.5 percentage points.

Specifically, we use a standard one-sector Neoclassical Growth Model based on

Hansen and Imrohoroglu (2016) to measure the additional revenue needed to stabilize government debt in the UK. Our proposed model assumes that the markets are complete and the agents have perfect foresight of exogenous variables such as government policy, population growth rates, production technology, and factor prices. Also, a stand-in household maximizes its utility given the budget constraint. We introduce the government bonds into the utility function by treating the UK as a closed economy, and the household holds all government bonds. The representative firm uses constant returns to scale the Cobb-Douglas production function to maximize its profits by choosing capital and labor. The government finances its exogenous purchases, transfer payments, and government debt by taxing household consumption, capital income, labor income, and interest on government bonds. The government is also subject to a debt sustainability rule that forces it to pay off its debt when the debt to output ratio hits the maximum level. Finally, all the markets need to be clear in equilibrium.

We calibrate the model to the UK economy using the actual time series for 1995-2015. In order to compute the transition path from the initial condition in 1995 to the steady-state, we extend the data to 2066 and above based on a series of assumptions and forecasting.

For the quantitative experiment, we experiment with several different ways to stabilize the debt. In our benchmark experiment, increasing lump-sum tax, which is equivalent to transfer payment reduction in our model, is used to achieve the goal. Specifically, when the debt to output ratio reaches its maximum level, the government is forced to retire the debt by increasing lump-sum tax (reducing transfer payment) to pay for the increases in government spending so that the debt to output ratio reduces and eventually drops down to its steady-state level. As the maximum level of debt to output ratio is exogenous in the model, we will consider different values of this ratio and explore how required revenues change among different values of the maximum level of debt to output ratio. In the fiscal policy experiments, a distorting tax such as consumption tax or labor income tax will be used instead of lump-sum tax to achieve our goal. We also consider tax system reforms by broadening the tax base in the fiscal policy experiments. We then compare the benchmark results with those obtained from fiscal policy experiments and provide the political suggestion for the fiscal reform for the UK government. We also examine the sensitivity of our results to different assumptions from the previous analysis.

The main finding of our research is that when the debt to output ratio reaches its maximum level, which is set to be 200% in the benchmark experiment, the revenue required as a share of consumption expenditures is in the range of 20%-24%. When the government uses consumption tax to finance the projected increases in government spending and bring the debt to output ratio to 60%, this tax rate needs to rise to over 50%. Even if the UK government broadens the tax base, it still requires the consumption tax rate to increase to over 40%. Additionally, if the labor income tax rate is considered to achieve the goal, unprecedented high levels of the tax rate of 70% without tax base broadening and 60% with tax base broadening need to be set up.

The rest of the paper is organized as follows. The next section presents the benchmark model. Section 2.3 discusses the measurement and calibration. The solution procedure is described in Section 2.4. The quantitative experiments are shown in Section 2.5, as well as the sensitivity analysis of the experiments. Finally, Section 2.6 provides a conclusion.

2.2 Benchmark Model

This section describes the Neoclassical Growth Model used in the benchmark simulation. The capital letter stands for per capita value. The model takes government purchases, transfer payments, total factor productivity, population, and tax rates as exogenous to determine the consumption, output, capital, government bond, bond price, investment, debt reduction, wage, working hour, and interest rate.

2.2.1 Household's Problem

We assume that the economy is closed, and the UK household holds all government debt.[2] There are N_t working-age members in the representative household at time t. The population growth is assumed as follow:

$$N_{t+1} = \Omega_t N_t \tag{2.1}$$

[2]The assumption is based on the fact that domestic investors hold approximately 70% of government bonds in the UK (DMO, 2012).

where Ω_t is a time-varying population growth rate.

The household is assumed to hold $B_0 > 0$, which is a one-period zero-coupon bond at time 0. Household has a preference on consumption, leisure, and holding government bonds, given by the utility function:

$$U_t = \sum_{t=0}^{\infty} \beta^t N_t \left[log(C_t) - \rho \frac{h_t^{1+1/\phi}}{1+1/\phi} + \theta log(\mu_t + B_{t+1}) \right] \tag{2.2}$$

where C_t is consumption, h_t is the fraction of hours worked, B_t is the quantity of one-period zero-coupon bonds purchased in period $t-1$, and maturing in period t, β denotes the subjective discount factor, $-\rho$ is the disutility of work and labor's inter-temporal elasticity of substitution is denoted by ϕ, θ denotes the household's preference for the government bond, μ_t measures other assets that might be perfect substitutes to the UK government bonds in generating utility to households. We add this parameter because it may be helpful to match the volatility of the bond prices.

The last term in the utility function captures the utility household derives from holding the government bond. By introducing the government bond in the utility function, both quantity and the price of government bonds are determined endogenously. Thus the well-known rate of return dominance of capital over government bonds can be yielded by the model.

Given the wage (W_t), the rental rate of capital (r_t), the price of bond (q_t), tax rates on consumption, labor income, capital income, and interest earnings on the government bonds ($\tau_{c,t}$, $\tau_{l,t}$, $\tau_{k,t}$, $\tau_{b,t}$), and transfer payment (T_t), the household's problem at time t is to choose paths of consumption (C_t), labor supply (h_t), capital stock (K_{t+1}), and bond holding (B_{t+1}) to maximize U_t given by Equation (2.2), subject to its budget constraint in period t, which is shown below:

$$\begin{aligned}(1-\tau_{l,t})W_t h_t + [1-(1-q_{t-1})\tau_{b,t}]B_t + [1+(1-\tau_{k,t})(r_t-\delta)]K_t + T_t \\ = (1+\tau_{c,t})C_t + q_t\Omega_t B_{t+1} + \Omega_t K_{t+1}\end{aligned} \tag{2.3}$$

where δ is the capital depreciation rate. Equation (2.3) implies that the household's consumption and the investments on capital and government bond at period t must be equal to its after-tax income of labor, capital, and bond from the previous period, and transfer payments from the government.

2.2.2 Firm's Problem

For production, we assume a Cobb-Douglas function which is shown in Equation (2.4):

$$N_tY_t = A_t(N_tK_t)^{\alpha}(N_th_t)^{1-\alpha} \tag{2.4}$$

where α is the income share of capital. The production function has constant returns to scale.

The law of motion for capital stock is

$$N_{t+1}K_{t+1} = (1-\delta)N_tK_t + N_tX_t \tag{2.5}$$

where X_t is the investment per capita.

The total factor productivity A_t as shown in Equation (2.6) is assumed to grow exogenously at the rate η_t:

$$A_{t+1} = \eta_tA_t \tag{2.6}$$

The stand-in firm maximizes its profit by choosing labor and capital.

2.2.3 Government

Government purchases, transfer payments, and government bonds are funded by issuing new bonds and tax revenues from household consumption, capital income, labor income, and interest earned on the government bonds. It can be described by the following government budget constraint:

$$G_t + T_t + B_t = q_t\Omega_tB_{t+1} + \tau_{c,t}C_t + \tau_{l,t}W_th_t + \tau_{k,t}(r_t-\delta)K_t + \tau_{b,t}(1-q_{t-1})B_t \tag{2.7}$$

The growth of government debt in our model is assumed to be restricted. That is, when the ratio of debt to output $br_t = B_t/Y_t$ reaches some specified value br_{max}, the government is required to reduce debt. This assumption is referred to as the debt sustainability rule, which can be described as the following equation:

$$D_t = \begin{cases} \kappa(B_t - B^*) & \text{if } br_s \geq br_{max} \text{ for some } s \leq t, \\ 0 & \text{others.} \end{cases} \tag{2.8}$$

where D_t is the amount of debt that government has to reduce, B^* is the steady-state level of the bond. Equation (2.8) works as follows: D_t is zero until the point that br_t reaches to the specified value br_{max}. At this point, subject to the debt sustainability rule, the government is forced to reduce the amount of debt $\kappa(B_t - B^*)$ so that the br_t could fall and ultimately converge to its steady-state value br^*. Parameter $\kappa > 0$ is chosen to be as small as possible to achieve this goal.

The debt sustainability rule plays a vital role in our model. First, it captures the fact that the amount of bonds the government can issue is restricted by its repayable ability in actual economies. Thus there exists an upper limit on how much debt the government can issue. It is not expected that the debt to output ratio to exceed this limit. Second, as we assume that the economy ultimately converges to its steady-state, the debt to output ratio is required to fall and converge to its steady-state level in our model. Without this assumption, convergence cannot be guaranteed.

In our benchmark model, we use lump-sum tax to finance the debt reduction. We assume that increasing lump-sum tax is equivalent to reducing the transfer payments. Therefore, when the government is forced to reduce debt, the transfer payments T_t in Equation (2.7) should be:

$$T_t = TR_t - D_t \tag{2.9}$$

where TR_t is the transfer payments under the circumstance where the government is not constrained by the debt sustainability rule.

2.2.4 General Equilibrium

Aggregating over agents and assuming market clearing allow us to derive a set of non-linear difference equations involving the endogenous variables and the parameters. The General Equilibrium of the model are obtained by satisfying the following conditions:

(i) the household maximizes utility subject to its budget constraint;

(ii) the firm maximizes profits with factor prices given by $W_t = (1-\alpha)A_t K_t^{\alpha} h_t^{-\alpha}$, and $r_t = \alpha A_t K_t^{\alpha-1} h_t^{1-\alpha}$;

(iii) the government budget constraint and debt sustainability rule hold;

(iv) the bonds market clears;

(v) the goods market clears: $C_t + X_t + G_t = Y_t$.

2.2.5 Detrended Equilibrium Conditions

In order to obtain the steady-state level of each variable, we need to derive the detrended equilibrium conditions for the economy. To do this, we assume that the economy converges to a balanced growth path where per capita aggregate variables grow at the rate $\eta_t^{1/(1-\alpha)}$, and we divide each variable by a scale factor that grows at its balanced growth rate. For instance, the detrended version of variable J_t is given by:

$$j_t = \frac{J_t}{A_t^{1/(1-\alpha)}} \tag{2.10}$$

The detrended equilibrium conditions are summarized in 10 equations, from Equation (2.11) to Equation (2.20), which are shown below.

The detrended Euler equation of consumption is given by Equation (2.11):

$$\frac{(1+\tau_{c,t+1})\eta_t^{1/(1-\alpha)} c_{t+1}}{(1+\tau_{c,t})c_t} = \beta[1 + (1-\tau_{k,t+1})(r_{t+1} - \delta)] \tag{2.11}$$

Equation (2.12) is the detrended bond Euler equation (dynamic optimality condition for bond):

$$\frac{\theta}{\mu + b_{t+1}} + \beta[1-(1-q_t)\tau_{b,t+1}]\frac{\Omega_t}{c_{t+1}(1+\tau_{c,t+1})} = \frac{q_t \Omega_t \eta_t^{1/(1-\alpha)}}{c_t(1+\tau_{c,t})} \tag{2.12}$$

The detrended first order condition for hours worked is given in Equation (2.13):

$$\rho h_t^{1/\phi} = \frac{(1-\tau_{l,t})w_t}{c_t(1+\tau_{c,t})} \tag{2.13}$$

The detrended production function and law of motion for capital are shown in Equations (2.14) and (2.15) respectively:

$$y_t = k_t^{\alpha} \cdot h_t^{1-\alpha} \tag{2.14}$$

$$\Omega_t \eta_t^{1/(1-\alpha)} k_{t+1} = (1-\delta)k_t + x_t \tag{2.15}$$

Equation (2.16) is the detrended budget constraint for the household:

$$\begin{aligned}(1+\tau_{c,t})c_t + \Omega_t \eta_t^{1/(1-\alpha)} k_{t+1} + q_t \Omega_t \eta_t^{1/(1-\alpha)} b_{t+1} &= (1-\tau_{l,t})w_t h_t \\ +[1+(1-\tau_{k,t})(r_t-\delta)]k_t + [1-(1-q_{t-1})\tau_{b,t}]b_t + tr_t - d_t\end{aligned} \tag{2.16}$$

The detrended government budget constraint is given below:

$$g_t + tr_t + b_t = q_t \Omega_t \eta_t^{1/(1-\alpha)} b_{t+1} + \tau_{c,t} c_t + \tau_{l,t} w_t h_t + \tau_{k,t}(r_t - \delta)k_t + \tau_{b,t}(1-q_{t-1})b_t + d_t \tag{2.17}$$

The detrended debt sustainability rule is given by Equation (2.18):

$$d_t = \begin{cases} \kappa(b_t - b^*) & \text{if } br_s \geq br_{max} \text{ for some } s \leq t, \\ 0 & \text{otherwise} \end{cases} \tag{2.18}$$

where b^* is the value of b_t along the balanced growth path, and it is equal to $br^* y^*$.

Finally, Equations (2.19), (2.20), (2.21) are the detrended market clearing conditions:

$$w_t = (1-\alpha)k_t^{\alpha} h_t^{-\alpha} \tag{2.19}$$

$$r_t = \alpha k_t^{\alpha-1} h_t^{1-\alpha} \tag{2.20}$$

$$y_t = c_t + x_t + g_t \tag{2.21}$$

2.3 Calibration

Before calculating the steady-state level of variables and transition path from the initial condition to a balanced growth path, it is essential to calibrate our model to the UK economy. The actual time series used in this paper are from ONS and The Organisation for Economic Co-operation and Development (OECD) database for 1995-2015. In addition, to compute the transition path from 1995 to the steady-state, we extend these series to 2066 and above based on the assumptions and forecasting.

2.3.1 Measurement

Product accounts. We use the methods provided by Hayashi and Prescott (2002) to adjust the variables. To be specific, output (Y) is GNI which includes income from foreign capital. Consumption (C) is total private final consumption expenditures. Investment (X) is adjusted to consist of gross private investment, trade balance, and net income from abroad.

In standard growth theory, all government purchases(G) are expensed. Thus government purchases in the product account include government consumption and investment. Table 2.1 explains how the product accounts are constructed exclusively from the adjusted National Accounts.

Table 2.1: Product accounts adjustments

C	=	Total private final consumption expenditures
X	=	Private gross capital formation + Trade balance + Net income from abroad
G	=	Total government final consumption expenditures + General government gross capital formation
Y	=	C+X+G

Capital Stock, K. Capital Stock excludes government capital but includes capital in foreign countries.[3]

Working-age population, N. The working-age population is defined as the number of people between 20 and 64.

[3]We calculate capital in foreign countries (KF) following the way of Hayashi and Prescott (2002): $KF(2012) = 25 *$ Net Income from Abroad (2012); $KF(t+1) = KF(t) +$ Trade Balance$(t) +$ Net Income from Abroad(t).

Average hours worked, h**.** This variable is calculated using the following equation: $h(t) = \frac{\text{Total actual weekly hours worked}(t)/N(t)}{48}$, where we assume the total discretionary hours available per week is 48, which is the legal maximum weekly working hours in the UK.

Tax rates. Following Mendoza et al. (1994), labor income tax rates (τ_l), and capital income tax rates (τ_k), are calculated as effective average tax rates on labor income and capital income, respectively. An effective average tax rate is defined as the ratio of tax revenue to pre-tax income. We can obtain the labor income tax using the following equation:

$$\tau_{l,t} = \left(\frac{\tau_{h,t} * w_t + TSS_t + TPW_t}{w_t + ESS_t}\right) * 100 \tag{2.22}$$

where w_t is wage, TSS_t and ESS_t are total social security contribution and employer's contribution to social security respectively, TPW_t defines taxes on payroll and workforce, $\tau_{h,t}$ is household's average tax rate on total income and we compute it as:

$$\tau_{h,t} = \left(\frac{TII_t}{MI_t + PEI_t + w_t}\right) * 100 \tag{2.23}$$

where TII_t is the tax on income, profits, and capital gains of individuals, MI_t denotes household's mixed income, and PEI_t is the household's property and entrepreneur income.

The effective tax rate on capital income (τ_k) follows:

$$\tau_{k,t} = \left[\frac{\tau_{h,t} * (MI_t + PEI_t) + TIC_t + TIP_t + TFC_t}{OS_t}\right] * 100 \tag{2.24}$$

where TIC_t, TIP_t, TFC_t are taxes on income, profits, and capital gains of corporations, recurrent taxes on immovable property, and taxes on financial and capital transactions, respectively. OS_t is the total operating surplus of the economy.

The consumption tax rate (τ_c) is equal to 17.6% from 1995 to 2010, except year 2009 in which $\tau_c = 15\%$, and from 2011 to 2015, $\tau_c = 20\%$.

For the tax rate on bond interest ($\tau_{b,t}$), we assume that it is equal to the household's average tax rate on total income ($\tau_{h,t}$).[4]

[4] This assumption is based on the fact that although any profit the investors make from buying and selling government bonds is exempt from Capital Gains Tax in the UK, it may still require investors to pay income tax on the interest they earn in excess of their personal savings allowance.

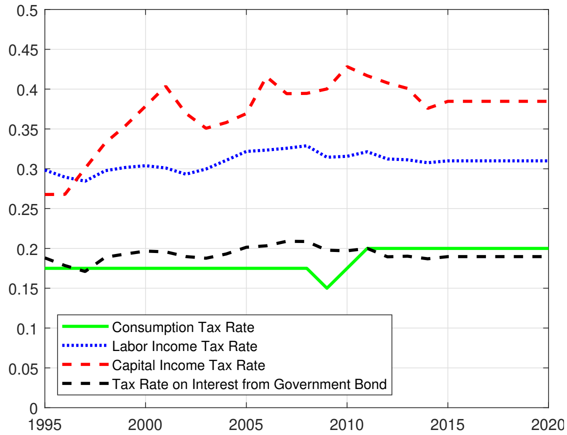


Figure 2.4: Tax Rrtes in benchmark calibration

Our benchmark experiment assumes that all tax rates are constant as their last observed values beyond 2015. Figure 2.4 shows the tax rates used in our benchmark experiment.

Government accounts. Public net debt (B) is measured as the difference between financial liabilities and assets of the Public Sector (excluding public sector banks). Interest payment on debt (P) is the product of GNI and the share of net public debt interest payments to national income. Transfer payments (TR) include public pensions and other social benefits (such as personal tax credits, housing benefits, jobseekers' allowance, and the equivalent support in the new universal credit paid to the unemployed) that did not count into G.

According to the OBR projection, the ratio of government purchases to output is forecast to increase by 5%, and the ratio of transfer payment to output is projected to increase by 2% from 2016 to 2066 (OBR, 2017).

In addition, since the tax rates we measured are not progressive and we also ignore the exclusions and deductions in the UK tax system, the tax revenue generated by the model is higher than the real tax revenue by around 3% of output. In order to be consistent with the actual data, we add this excess revenue to transfer payments in our measurement. In some later fiscal policy experiments, we will allow the government to broaden its tax base by eliminating this excess revenue from transfer payments.

Population growth rate, Ω_t. Population growth rate for 1995-2066 can be calculated using Equation (2.1) with the actual and projected data of N produced by ONS.

we assume that the population growth rate is equal to one after 2066, which implies that the population is assumed to remain constant.

Capital income share, α. We assume that the capital income share is constant across time, and it measures as the sample average of the share of capital income in output during 1995-2015.[5] The value of α is 0.3734.

The growth rate of total factor productivity, η_t. Given $\{N_t, Y_t, K_t, h_t\}$ as well as α, the total factor productivity (A_t) can be calculated using Equation (2.4), then the growth rate of total factor productivity for 1995-2014 can be obtained by Equation (2.6). We assume this growth rate is constant and equal to $1.011^{1-\alpha}$ from 2015 and above.[6]

Depreciation rate, δ. According to Hayashi and Prescott (2002), the capital depreciation rate can be measured as the sample average of the ratio of depreciation to capital stock for 1995-2015, where the depreciation is defined as the total consumption of fixed capital. The value of δ is 0.0365.

The elasticity of labor supply, ϕ. Following the estimation of intertemporal substitution elasticity in Chetty et al. (2013), we set $\phi = 0.5$ in our model.

Preference parameters, β, ρ, θ, and μ. The first three parameters β, ρ, θ can be calculated using the following equilibrium conditions, and the average value is taken in the model:

$$\beta_t = \frac{(1+\tau_{c,t+1})\eta_t^{1/(1-\alpha)} c_{t+1}}{(1+\tau_{c,t})c_t[1+(1-\tau_{k,t+1})(\alpha\frac{y_{t+1}}{k_{t+1}} - \delta)]} \tag{2.25}$$

$$\rho_t = \frac{h_t^{-1/\phi}(1-\tau_{l,t})(1-\alpha)y_t}{(1+\tau_{c,t})c_t h_t} \tag{2.26}$$

$$\theta_t = \Omega_t(\mu + b_{t+1})\left[\frac{q_t \eta_t^{1/(1-\alpha)}}{(1+\tau_{c,t})c_t} - \frac{\beta[1-(1-q_t)\tau_{b,t+1}]}{(1+\tau_{c,t+1})c_{t+1}}\right] \tag{2.27}$$

As B is a one period zero-coupon bond in our model, we compute the price of government bonds (q_t) in Equation (2.27) as:

[5] Following Hayashi and Prescott (2002), capital income is defined as the sum of the gross operating surplus of corporations and households, 20 percent of the gross operating surplus of non-households, 50 percent of indirect business taxes, and net factor payments from abroad.

[6] With a constant rate of technological growth, all economies converge toward a balanced growth path. Along the balanced growth path, the constant growth rate of capital per worker and output per worker is given by $\frac{k_{t+1}}{k_t} = \frac{y_{t+1}}{yt} = (\eta^*)^{1/(1-\alpha)}$, where η^* is the growth rate of total factor productivity in the steady state. We assume the growth rate of the economy is 1.1%, thus η^* is $1.011^{1-\alpha}$.

$$q_t = \frac{B_{t+1}/F_t}{(B_{t+1} + P_{t+1})/F_{t+1}} \tag{2.28}$$

where B_t is beginning of period debt, P_t denotes interest payments of government bonds in period t, F_t is the GNI deflator.

The last preference parameter (μ) is the detrended value of μ_t. We choose it to minimize the sum of squared differences between the bond price generated by the model and its data counterpart. This parameter would help us to match the volatility of the bonds price.

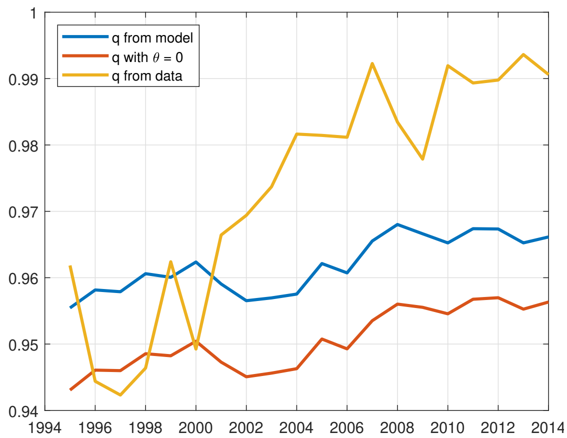


Figure 2.5: Bond prices from UK data and benchmark simulation

Figure 2.5 shows the price of government bonds generated by our model and its counterpart calculated using Equation (2.28), as well as the price when $\theta = 0$. With $\theta = 0$, the government bonds have the same rate of return as capital. Figure 2.6 shows the before and after-tax rates of return on government bonds and capital generated by the model. From these two figures, we can see that the household is willing to hold government bonds at a higher price and lower rate of return when $\theta > 0$, compared to when $\theta = 0$. Figure 2.6 also shows the notable feature that the rate of return of capital always dominates that of government bonds. Table 2.2 reports the calibrated values of the structural parameters in our benchmark model.

Table 2.2: Parameters values used in simulations

Parameter	Value	Description
α	0.3734	Capital income share, sample average, 1995-2015
δ	0.0365	Depreciation rate, sample average, 1995-2015
ϕ	0.5	Labor supply elasticity, Chetty et al. (2013)
β	0.9769	Household's subjective discount factor, sample average
ρ	3.77	Disutility of work, sample average
θ	0.0252	Household's preferences for government bonds, sample average
μ	1.5	Fit q_t for 1995-2015

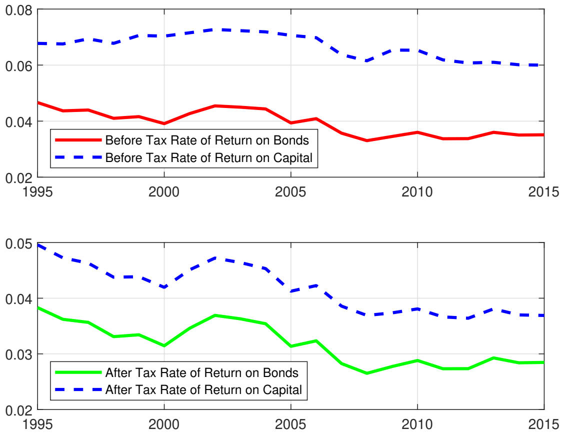


Figure 2.6: Returns on capital and bonds from benchmark simulation

2.4 Solution Procedure

After calibration, we can now use the model to calculate the steady state level of the economy and transition path from the initial condition to a balanced growth path, following the methodology of Hayashi and Prescott (2002). The simulation takes the capital stock $(\frac{k}{y})_{t=1995}$ and a sequence $\{(\frac{g}{y})_t, (\frac{tr}{y})_t, \tau_{c,t}, \tau_{l,t}, \tau_{k,t}, \tau_{b,t}, \eta_t, \Omega_t\}_{t=1995}^{\infty}$ as given. A forward shooting algorithm is used to calculate the transition path. The computation Objective is to find value for $c_{t=1995}$ so that the endogenous variables $\{c_t, k_{t+1}, b_{t+1}, d_t, y_t, x_t, h_t, q_t, w_t, r_t\}$ could converge to their steady state values. Specifically, we initially set $c_H = f((\frac{k}{y})_{t=1995})$ and $c_L = 0$. We choose a stopping criterion $\varepsilon > 0$. The first step is to set $c(0) = c_{t=1995} = (c_L + c_H)/2$. In the second step, we start shooting by solving Euler equation and labor leisure choice with initial conditions $c(0)$, $\frac{k}{y}(0) = (\frac{k}{y})_{t=1995}$; stop the algorithm at the first t when the growth rate $\frac{c(t)}{c(t-1)} < 0$ or $\frac{k(t)}{k(t-1)} < 0$, and denote it as T. Step 3 is to check convergence and update $c(0)$: If $|c(T) - c^*| < \varepsilon$ where c^* is the steady state level of consumption , stop. Otherwise, if $\frac{c(t)}{c(t-1)} < 0$, then set $c_L = c_{t=1995}$; else set $c_H = c_{t=1995}$ and go back to first step.

2.5 Quantitative Findings

This section presents the numerical results. As mentioned in Section 2.2, the government is subject to the debt sustainability rule, which forces the government to reduce its debt when the debt to output ratio reaches a specific value br_{max}. In the benchmark experiment, the debt reduction is financed by increasing lump-sum tax (reducing transfer payments). Furthermore, We implement four fiscal policy experiments, where the labor income tax or consumption tax will be used as the major fiscal instrument to increase the tax revenue and stabilize the debt. Finally, we conduct several sensitivity analyses by considering some alternative calibrations and policy options.

2.5.1 Benchmark Experiment

In this subsection, We experiment with three different values of br_{max}, which are 150%, 200%, and 250%. According to the historical data of debt to output ratio, the national debt reached around 250% of GDP in 1816 after the battle of Waterloo, and the same situation happened after the close of World War II in 1947. Also, OBR predicts that the debt to output ratio will exceed 200% in the UK after 2061. Therefore, the values of br_{max} we choose are reasonable, although they are much higher than the current level of debt of output ratio.

The steady-state level of debt to output ratio (br^*) is assumed to be equal to 60%, which is the convergence criteria of debt-GNI-ratio in the Maastricht Treaty that force all the EU members to abide by.

For each value of br_{max}, we experiment with different values of κ, and the smallest value is chosen so that the debt to output ratio could converge to its steady-state level.

Figure 2.7 shows how we choose the parameter κ when $br_{max} = 200\%$. The debt sustainability rule is triggered in 2033, where the government is forced to begin to reduce the debt, which is equal to $\kappa(b_t - br^* y^*)$. The upper panel of Figure 2.7 shows that $\kappa = 0.05$ is insufficient to achieve debt sustainability as the debt to output ratio continues to grow after 2033, whereas the larger values of κ which are 0.09 and 0.15, can stabilize the ratio. The lower panel of Figure 2.7 shows the additional lump-sum tax required to retire debt as a fraction of consumption expenditures for different values of κ. The revenue requirement (D_t) is positive as long as the debt exceeds its steady-state value. As the difference between the debt and its steady-state value becomes smaller, the revenue requirement declines and eventually converges to zero. Furthermore, the debt to output ratio drops faster if $\kappa = 0.15$, but it needs more revenue in the triggered date than necessary. We choose $\kappa = 0.09$ for $br_{max} = 200\%$ because it is the smallest value that can guarantee the convergence.

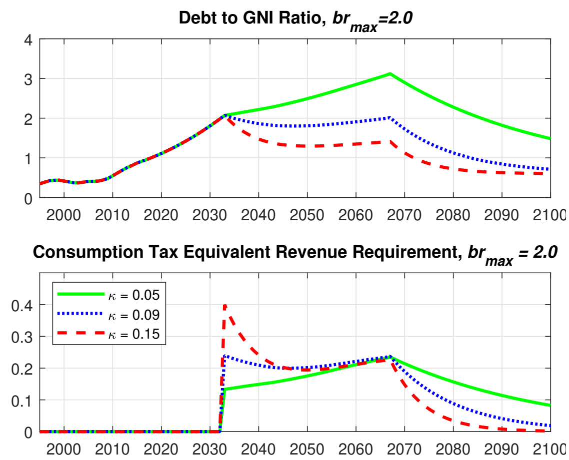


Figure 2.7: B_t/Y_t and D_t/C_t in the benchmark economy

Figure 2.8 and Figure 2.9 depict the paths of the debt to output ratio and the revenue requirements for different values of br_{max}. We choose $\kappa = 0.13$ when $br_{max} = 150\%$ and $\kappa = 0.07$ when $br_{max} = 250\%$. The triggered years are 2027 and 2038, respectively. As expected, the higher is br_{max}, the later the debt sustainability rule is activated. In addition, the tax revenue required to stabilize debt is in the range of 20%- 24% of aggregate consumption expenditures when $br_{max} = 200\%$ and it increases with the value of br_{max}.[7]

[7] The revenue requirements are 17%- 23% and 24%- 26%, when $br_{max} = 150\%$ and $br_{max} = 250\%$,

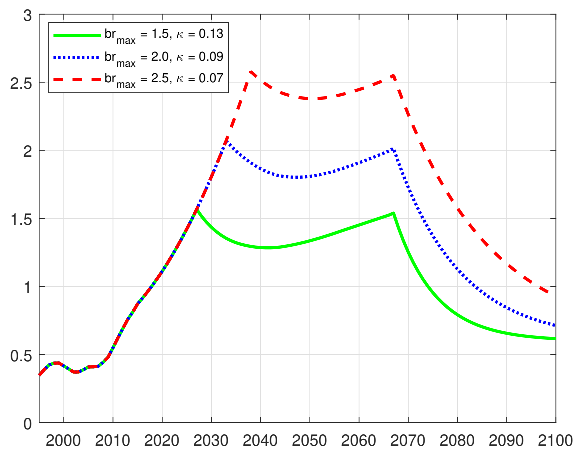


Figure 2.8: Time paths for debt to output ratio in the benchmark economy

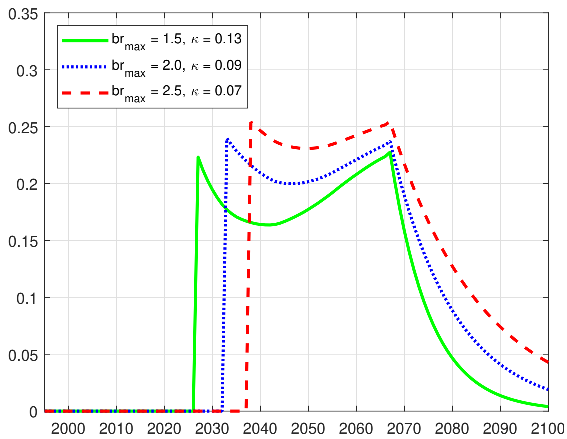


Figure 2.9: Revenue requirement as fraction of aggregate consumption in the benchmark economy

In order to evaluate the performance of our model, we display and compare the time paths in the data and in the benchmark exercise where $br_{max} = 200\%$ and $br^* = 60\%$. Figure 2.10 shows hours worked, capital stock, and output in the data and the benchmark exercise. We normalize capital stock and output by setting 1995 values equal to 100. It is easy to discover from Figure 2.10 that when compared to the performance after 2007, the model generates the data better matching with the actual data during 1995-2007. It

respectively.

may be due to the financial crisis of 2007-2008, which is a feature that is not considered in our model.

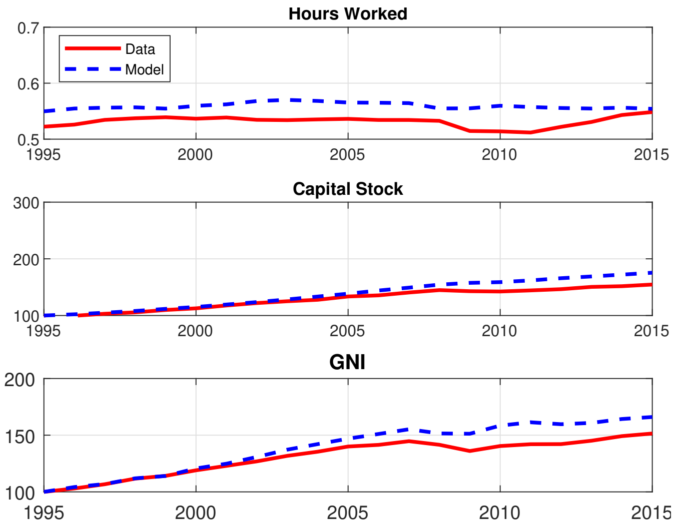


Figure 2.10: Labor, capital, and output: UK data and the benchmark economy

Figure 2.11 depicts the paths of consumption, investment, and the capital-output ratio in the actual data and in the model, where the values of consumption and investment in 1995 are normalized to equal to 100. The model performs reasonably well in terms of replicating consumption behavior and capital-output ratio. However, it captures a higher investment behavior than that in the actual UK economy.[8]

Figure 2.12 displays the data and model debt-output ratio. As we mentioned above, we assume that 3% of output is added to transfer payments because the tax rates in our model are flat, and they ignore the exemptions and deductions in the UK tax code. By doing so, the debt to output ratio generated by the model is much closer to that in the actual data.

[8]According to Imrohoroglu and Sudo (2011a), it may be because our model does not capture the change in productivity, which is a key element of the investment goods sector.

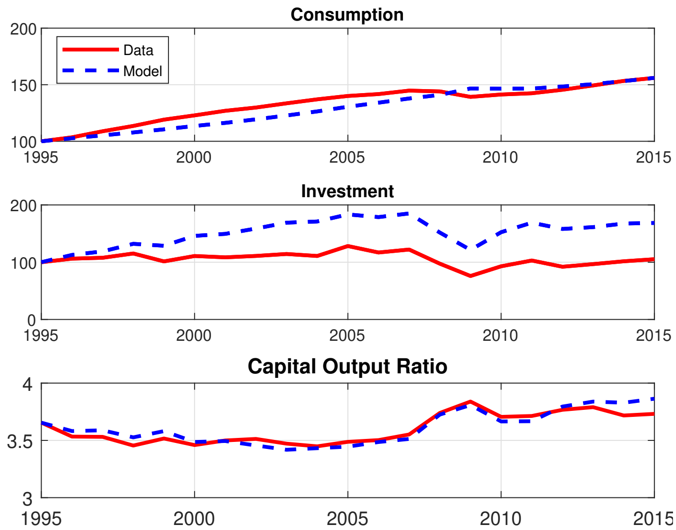


Figure 2.11: Consumption, investment, and capital-output Ratio: UK data and the benchmark economy

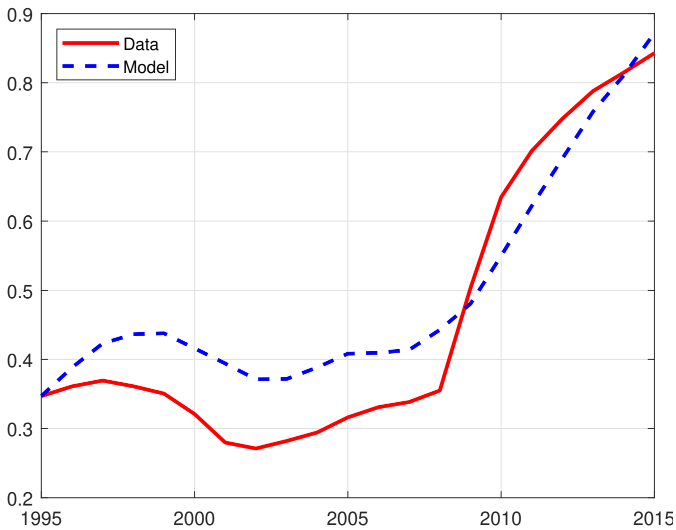


Figure 2.12: Net debt to GNI ratio: UK data and the benchmark economy

2.5.2 Fiscal Policy Experiments

Unlike the benchmark exercise in which lump-sum tax is increased to raise sufficient revenue to achieve fiscal stability, this subsection conducts several experiments that aim to achieve fiscal stability using the revenue that comes from increasing distorting tax rate such as consumption tax rate or labor income tax rate.[9]

We consider two cases: In Experiments 1- 2, the consumption tax rate is the primary instrument of achieving debt stability, whereas in Experiments 3- 4, the labor income tax rate is used to reach the target. We denote the tax rate used as a primary fiscal instrument as $\tau_{x,t}$ and the steady-state level of $\tau_{x,t}$ is $\bar{\tau}_x$ which is endogenously determined by the model. We assume that all the tax rates are initially equal to their benchmark values until the debt to output ratio (br) reaches its threshold level (br_{max}). At this point, all the tax rates remain to their benchmark values, except $\tau_{x,t}$ which is increased by an amount ν to finance the additional government spending and reduce the debt. The parameter $\nu > 0$ is assigned to be as small as possible so that the debt to output ratio (br_t) could converge to its steady-state level (br^*) eventually. When br^* has reached, the primary instrument tax rate is reduced and is assumed to be equal to its steady-state value. The primary instrument tax rate can be expressed as the following equation:

$$\tau_{x,t} = \begin{cases} \tau_{x,t}^B & \text{if } br_s \leq br_{max} \text{ for all } s \leq t \\ \bar{\tau}_x + \nu & \text{if } br_s > br_{max} \text{ for some } s \leq t \text{ and } br_t > br^* \\ \bar{\tau}_x & \text{if } br_t \leq br^* \end{cases} \tag{2.29}$$

where $\tau_{x,t}$ is $\tau_{c,t}$ in Experiments 1-2 and is $\tau_{l,t}$ in Experiments 3-4, $\tau_{x,t}^B$ is the benchmark value of $\tau_{x,t}$.

Since the tax rates measured in our research are flat rates and we ignore the exclusions and deductions in the UK tax system, the tax revenue generated by the model is higher than the real tax revenue by around 3% of output. In the benchmark experiment, we add this excess revenue to transfer payments, whereas in some of the experiments in this subsection, however, we allow the government to broaden its tax base by eliminating this excess revenue from transfer payments to lower the level of debt. To be specific, the transfer payment (TR_t^B) is assumed to be equal to its benchmark value initially, until the ratio of debt to output reaches its maximum level, br_{max}. At this point, the government is allowed to reduce $0.03Y_t$ from TR_t. In other word, $TR_t = TR_t^B - 0.03Y_t$, where TR_t^B is the benchmark value of transfer payment.

[9]The reason we choose these two distorting taxes is that they are not as distortionary as the capital income tax in our case.

The fiscal policy experiments are summarized in Table 2.3 and 2.4, where Experiments 1-2 are displayed in Table 2.3 and Experiments 3-4 are presented in Table 2.4. In Experiment 2 and Experiment 4, the UK government can broaden its tax base by reducing the transfer payments when the debt to output ratio reaches its threshold level. In our fiscal policy experiments, we assume that the steady-state level of the debt to output ratio (br^*) is equal to 60% and the threshold level of the debt to output ratio (br_{max}) is 200%. In the next subsection, we relax these assumptions to test the sensitivity of our results.

Table 2.3: Characterization of fiscal experiments: τ_c set according to Eq.(2.29

Experiment 1	$\tau^1_{c,t} = \begin{cases} \tau^B_{c,t} & t < T_1, \\ \bar{\tau}^1_c + \nu_1 & T_1 \le t < T_2, \\ \bar{\tau}^1_c & t \ge T_2. \end{cases}$
	$\tau^1_{l,t} = \tau^B_{l,t}$ for all t,
	$TR^1_t = TR^B_t$ for all t,
Experiment 2	$\tau^2_{c,t} = \begin{cases} \tau^B_{c,t} & t < T_1, \\ \bar{\tau}^2_c + \nu_2 & T_1 \le t < T_2, \\ \bar{\tau}^2_c & t \ge T_2. \end{cases}$
	$\tau^2_{l,t} = \tau^B_{l,t}$ for all t,
	$TR^2_t = \begin{cases} TR^B_t & t < T_1, \\ TR_t - 0.03Y_t & t \ge T_1. \end{cases}$

T_1: Date when B/Y reaches 200%.
T_2: Date whenB/Y is less than or equal to steady state value.
$\tau^i_{c,t}$: Consumption tax rate at date t in Experiment i.
$\tau^i_{l,t}$: Labor income tax rate at date t in Experiment i.
TR^i_t: Transfers at date t in Experiment i.
$\bar{\tau}^i_c$: Steady state consumption tax rate in Experiment i.
ν_i: Increment to consumption tax during transition to steady state.

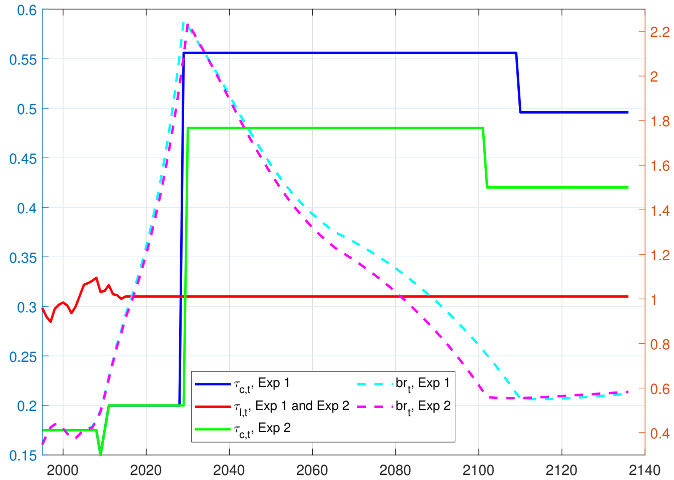
Table 2.4: Characterization of fiscal experiments: τ_l set according to Eq.(2.29)

Experiment 3	$\tau^3_{l,t} = \begin{cases} \tau^B_{l,t} & t < T_1, \\ \bar{\tau}^3_l + \nu_3 & T_1 \leq t < T_2, \\ \bar{\tau}^3_l & t \geq T_2. \end{cases}$
	$\tau^3_{c,t} = \tau^B_{c,t}$ for all t,
	$TR^3_t = TR^B_t$ for all t,
Experiment 4	$\tau^4_{l,t} = \begin{cases} \tau^B_{l,t} & t < T_1, \\ \bar{\tau}^4_l + \nu_4 & T_1 \leq t < T_2, \\ \bar{\tau}^4_l & t \geq T_2. \end{cases}$
	$\tau^4_{c,t} = \tau^B_{c,t}$ for all t,
	$TR^4_t = \begin{cases} TR^B_t & t < T_1, \\ TR_t - 0.03Y & t \geq T_1. \end{cases}$

Notation same as in Table 2.3.
$\bar{\tau}^i_l$: Steady state labor tax rate in Experiment i.
ν_i: Increment to labor income tax during transition to steady state.

Figure 2.13 presents the changes in consumption tax and debt-to-GDP ratio in Experiments 1-2. The consumption tax rate in Experiment 1 is the major tax instrument to pay for future expenditures. According to Figure 2.13, the consumption tax is equal to its benchmark value until 2029 when the debt to output ratio reaches 209%, exceeding its threshold level of 200%. At this point, the consumption tax rate needs to increase significantly from 20% to 55.59% in order to reduce the fiscal burden from expenditures. When the debt to output ratio converges to 60% at $T_2 = 2110$, the consumption tax reduces to its steady-state level, which is $\bar{\tau}^1_c = 49.59\%$.

When considering the tax broadening by reducing transfer payments by 3% of output in Experiment 2, the consumption tax rate does not need to increase as much as in Experiment 1. In this case, the threshold point is hit at $T_1 = 2030$. Before 2030, the consumption tax rate is the same as that in Experiment 1 and is equal to its benchmark value, whereas, in 2030, the consumption tax rate is raised from 20% to 48% and reaches 42% at $T_2 = 2102$ and remains at this level from then on. Compared with Experiment 1, the lower required consumption tax rate in Experiment 2 indicates that broadening the tax base could help reduce the level of debt so that the government does not need as



Note: Tax rates (left-hand scale); Debt-to-GDP ratios (right-hand scale).

Figure 2.13: τ_c and τ_l in Experiments 1 and 2

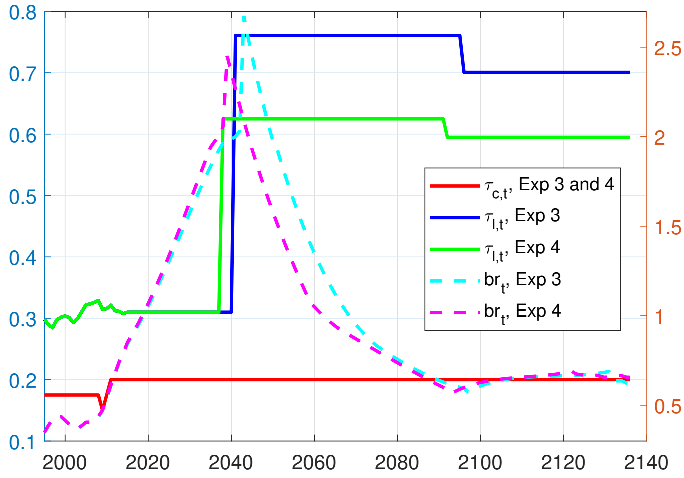
much consumption tax as Experiment 1 to finance the fiscal burden.

Figure 2.13 also shows the time paths of labor income tax rate ($\tau_{l,t}$) from 1995 to 2038. The time paths of labor income tax rate in Experiments 1 and 2 are assumed to be the same as in the benchmark experiment.

Figure 2.14 depicts the time paths of consumption tax rate, labor income tax rate, and debt-to-GDP ratio in Experiment 3 and 4, where the labor income tax rate is used as a primary instrument to lower the debt to output ratio to 60%. The consumption tax rates in both experiments are maintained as that in the benchmark experiment.

The only difference between Experiments 3-4 is that we allow both labor income tax rate and tax broadening to be used to increase the tax revenue in Experiment 4, while Experiment 3 only considers labor income tax rate as the fiscal policy to achieve the goal.

In Experiment 3, the first trigger year is $T_1 = 2041$, when the debt to output ratio reaches 200%. In order to finance the future government expenditures and reduce the fiscal burden to 60%, the labor income tax rate needs to increase sharply to 76.07% in 2041 and keep at this level until the debt to output ratio reduces and converges to its steady-state level at $T_2 = 2096$. At this point, the labor income tax rate drops to equal its steady-state level, which is $\bar{\tau}_l^3 = 70.07\%$.



Note: Tax rates (left-hand scale); Debt-to-GDP ratios (right-hand scale).

Figure 2.14: τ_c and τ_l in Experiments 3 and 4

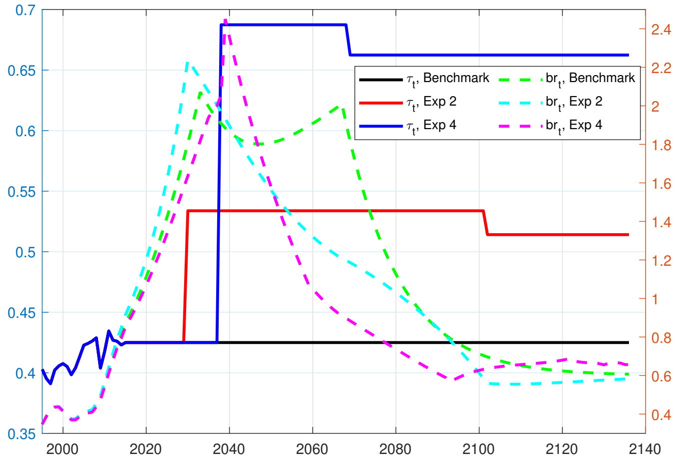
With tax broadening, the revenue required to pay for the expenditures is lower than in Experiment 3. Therefore, the labor income tax rate needed to increase the tax revenue in Experiment 4 is lower than that in Experiment 3. Specifically, the labor income tax rate in Experiment 4 rises from 31% to 62.49% at $T_1 = 2038$, when the debt-to-GDP ratio hits 200%. The ratio then starts to reduce and when it reaches its steady-state level at $T_2 = 2092$, the labor income tax rate drops to and remains at its steady-state level of 59.49%.

Additionally, we attempt to compare the results of model simulations under benchmark policy and two fiscal policies where the government is allowed to broaden its tax base (Experiment 2 and 4).

Before we display the response of the economy to these three policies, it is necessary to compare their effective tax rates first. As seen from Equation (2.13), both consumption and labor income tax rates could distort the labor supply. We define an effective tax rate (τ_t) as a function of $\tau_{c,t}$ and $\tau_{l,t}$ using Equation (2.30):

$$(1-\tau_t) = \frac{(1-\tau_{l,t})}{(1+\tau_{c,t})} \tag{2.30}$$

The effective tax rate measures the tax distortions created by different combinations



Note: Tax rates (left-hand scale); Debt-to-GDP ratios (right-hand scale).

Figure 2.15: Effective tax rate (τ_t) in the benchmark economy and Experiments 2 and 4

of $\tau_{l,t}$ and $\tau_{c,t}$. The higher the effective tax rate is, the larger is the extent of tax distortion. According to Figure 2.15, the effective tax rate in the benchmark experiment is lower than those in two selected fiscal policy experiments. This is because the fiscal instrument in the benchmark experiment is a lump-sum tax which is not as distortionary as consumption tax rate or labor income tax rate, which is used as the major fiscal instrument to mitigate the fiscal pressure in the fiscal policy experiment.

Compared with the effective tax rate obtained in Experiment 2, where the consumption tax is the primary fiscal policy to raise the revenue and lower the debt to output ratio, the effective tax rate in Experiment 4 is much higher after the threshold point where the debt to output ratio reaches 200%. It indicates that the labor distortion is higher in Experiment 4 than that in Experiment 2.

Figure 2.16 and Figure 2.17 show the results of model simulations in the benchmark experiment, Experiment 2 and Experiment 4. Figure 2.16 displays the time paths of consumption and investment from 2010 and afterward. Unlike those in the two fiscal policy experiments, the consumption and investment in the benchmark experiment increase steadily, and there is no sharp increase or decline in these two variables.

In Experiment 2, the household anticipates that the consumption tax rate needs to rise significantly to finance the government expenditures in 2030 so that the household reduces the investment and increases the current consumption. When the consumption

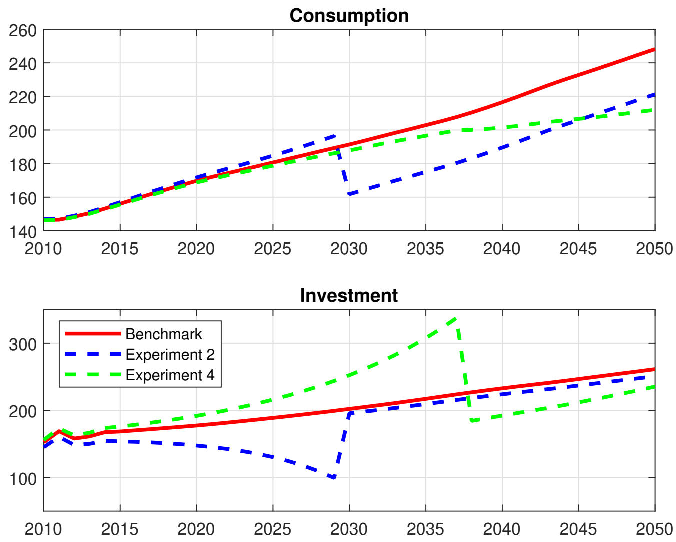


Figure 2.16: Model consumption and investment

tax rises in 2030, the consumption drops dramatically, while investment increases significantly.

In Experiment 4, an increase in the labor income tax rate in 2038 reduces the labor supply, and hence the household's labor income slows down the consumption growth. Meanwhile, the household expects a decline in the future labor income so that the household increases the current saving. That is why we can see a sharp increase in investment prior to 2038. When the labor income tax increases to a very high level in 2038, the investment declines significantly.

Figure 2.17 demonstrates a significant reduction in hours worked in Experiment 4, compared to a modest decline in Experiment 2, indicating that the distortion on labor supply in Experiment 4 is much higher than that in Experiment 2. The changes in capital stock and output time paths depend on the changes in hours worked and investment.

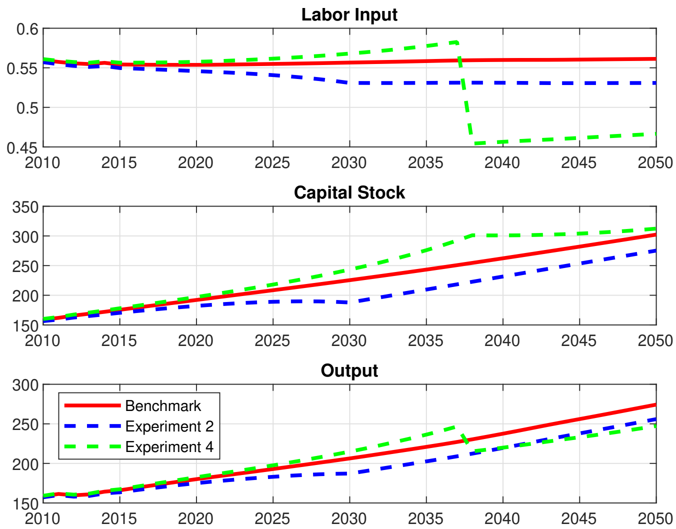


Figure 2.17: Model labor, capital, and output

2.5.3 Sensitivity Analysis

This subsection provides the sensitivity analysis of our results to different assumptions from the previous analysis. First, we study the effect of alternative assumptions of the labor supply elasticity (ϕ) on our results. Second, we apply different values of the maximum level of debt to output ratio (br_{max}) and/or steady-state level of debt to output ratio (br^*) to see how the outcomes of experiments change with them. Finally, we explore the impact of economic growth reflected by different values of total factor productivity growth rate on our findings.

Labor Supply Elasticity. The intertemporal elasticity of substitution of labor supply (ϕ) used in our previous calibration is the Frisch elasticity of labor supply set to be 0.5. In this subsection, we apply a lower value of the Frisch elasticity of labor supply, $\phi = 0.25$, to Experiments 2 and 4 and compare the results with those obtained in Section 2.5.2. The results are shown in Table 2.5.

Table 2.5 reports the dates when debt to output ratio reaches 200% (T_1), the dates when its ratio is less than or equal to steady state value (T_2), and their corresponding consumption tax rates, labor income tax rates, and effective tax rates in Experiment 2 and 4 for both cases when $\phi = 0.5$ and $\phi = 0.25$.

Table 2.5: Frisch elasticity and equilibrium tax rates

	Exp2		Exp4	
	$\phi = 0.5$	$\phi = 0.25$	$\phi = 0.5$	$\phi = 0.25$
T_1	2030	2030	2038	2035
τ_{c,T_1}	48.01%	44.65%	20.00%	20.00%
τ_{l,T_1}	31.00%	31.00%	62.49%	54.86%
τ_{T_1}	53.38%	52.30%	68.74%	62.39%
T_2	2102	2111	2069	2084
τ_{c,T_2}	42.01%	39.65%	20.00%	20.00%
τ_{l,T_2}	31.00%	31.00%	59.49%	50.86%
τ_{T_2}	51.41%	50.59%	66.24%	59.05%

The smaller value of Frisch elasticity of labor supply (ϕ) implies the labor supply is more inelastic responding to the consumption tax rate or labor income tax rate.[10] In Experiment 2, with a constant labor tax rate during the transition path and steady state path, a lower Frisch elasticity of labor supply means the labor supply in the economy is less distorted by the consumption tax rate, hence both of the effective tax rates in the first triggered date and in the second triggered date are smaller when $\phi = 0.25$ than those in the case when $\phi = 0.5$. According to Equation (2.30), with a constant labor tax rate, the lower effective tax rates the lower consumption tax rate is, hence we can obtain smaller values of τ_{c,T_1} as well as τ_{c,T_2} in the case when $\phi = 0.25$, compared with the case when $\phi = 0.5$. Recall that the date when the debt to output ratio converges to its steady state level is $T_2 = 2102$ in the case of $\phi = 0.5$. Because the consumption tax in the first triggered date becomes smaller when $\phi = 0.25$, we do not have as much tax revenue as the case when $\phi = 0.5$ to finance the future expenditure and as a result, the debt to output ratio cannot converge to 60% at 2102 and it needs longer time to achieve the convergence. The second triggered date is 2111 when $\phi = 0.25$.

As with Experiment 2, when $\phi = 0.25$, the lower Frisch elasticity results in a smaller distortion in labor supply, and therefore the effective tax rates and their corresponding labor tax rates are not as high as those in the case when $\phi = 0.5$. In addition, as discussed

[10]The elasticity of the labor supply with respect to the tax rate can be computed using the following equation: $e(\tau_n) \equiv -\frac{\partial h(\tau_n)}{\partial \tau_n} \frac{\tau_n}{h(\tau_n)}$. Thus, according to Equation (2.13), the elasticity of the labor supply with respect to the consumption tax rate is $e(\tau_c) = \frac{\phi}{1+\frac{1}{\tau_c}}$, and the elasticity of the labor supply with respect to the labor income tax rate is $e(\tau_l) = \frac{\phi}{1+\frac{1}{\tau_l}}$.

in Section 2.5.2, the labor distortion in Experiment 4 is larger than that in Experiment 2. Thus the rates of decline in labor income tax rates are greater at both T_1 and T_2 in Experiment 4, compared to the rates of decline in consumption income tax rates in Experiment 2 when assuming a smaller labor supply elasticity.

The Debt to Output Ratio. In this subsection, we will evaluate the performance of the consumption tax rate in Experiment 2 by experimenting with the different values of br_{max} and/or br^*. We choose two different combinations of br_{max} and br^* for Experiment 2 and we show the first triggered date (T_1), second triggered date (T_2) and their corresponding consumption tax rates of each combination in Table 2.6.

Table 2.6: Experiment 2 with alternative debt to output ratios

	$br_{max} = 200\%$ $br^* = 60\%$ (baseline case)	$br_{max} = 200\%$ $br^* = 100\%$	$br_{max} = 150\%$ $br^* = 80\%$
T_1	2030	2030	2023
τ_{c,T_1}	48.01%	46.75%	52.85%
T_2	2102	2129	2035
τ_{c,T_2}	42.01%	43.75%	42.85%

The second column of Table 2.6 displays the baseline result we obtained in Experiment 2 in Section 2.5.2. We then increase br^* to 100% but keep br_{max} to be constant in the third column of Table 2.6. When the maximum level of debt to output ratio is remained, with a higher steady-state level of debt to output ratio, the government does not need to raise much revenue to reach a lower steady-state level of debt to output ratio. Hence we obtain a lower consumption tax rate during the transition period. However, as a higher debt in the steady-state, a higher consumption tax rate is required to finance it. Thus we obtain a higher consumption tax rate in the steady-state.

In the last column of Table 2.6, we apply a lower br_{max} which is set to 150% while a higher br^* of 80% relative to those in the baseline case. According to Figure 2.9, with a smaller maximum level of debt to output ratio, the first triggered date is earlier. In this case, the consumption tax rate during the transition period is higher at 52.85% compared to the baseline value of 48.01%. By reducing br_{max}, the trigger point is acted much sooner, and the length of the transition path is much shorter so that the government needs to raise a higher consumption tax rate during such a shorter transition period relative to the baseline case.

Higher Productivity Growth. As mentioned above, Imrohoroglu and Sudo (2011a) consider different balanced growth rates which are driven by TFP growth rates to test how fast the economy should grow to cover the increasing government expenditure. In this subsection, we do similar experiments as Imrohoroglu and Sudo (2011a). According to Imrohoroglu and Sudo (2011a), the higher economic growth rate would increase the government revenue to finance the government expenditure. In our case, the UK government does not need to impose that much consumption tax if economic growth accelerates.

In our previous calibrations, we assume the economic growth rate is 1.1% from 2015 and above. Thus the total factor productivity growth rate η_{2015}^{∞} is constant and equals to $1.011^{1-\alpha}$. In this subsection, we explore how our results change with different values of TFP growth rate in Experiment 2. First, we allow the TFP growth rate to change temperately, and then we consider the effect of a permanent change in the TFP growth rate.

The results are shown in Table 2.7 where we display the first and second triggered dates and their corresponding consumption tax rates as well as the output growth rate of each experiment. The first line is the baseline result of Experiment 2. In the second row, we assume that the economic growth rate in Experiment 2 is temperately reduced to 0% from 2020 to 2044, and after that, it is back to 1.1%. The third and fourth rows show the results of the experiments where the economic growth rates are temperately increased to 1.5% and 2%, separately, from 2020 to 2044, and they are assumed back to 1.1% and remain so after 2044. As the steady-state level of economic growth rate has not changed in these three experiments, the steady-state level of the consumption tax rate is the same as that in the baseline case, which is 42.01%. The temperate changes in economic growth only affect the consumption tax rate during the transition period: The consumption tax rate is higher if the balanced growth rate is lower than that in Experiment 2 and vice versa.

Table 2.7: Experiment 2 with different growth rates

	T_1	τ_{c,T_1}	T_2	τ_{c,T_2}	g_{GNI}
$\{\eta_t\}_{t=2016}^{\infty} = 1.011^{1-\alpha}$ (Experiment 2)	2030	48.01%	2102	42.01%	1.0941
$\{\eta_t\}_{t=2020}^{2044} = 1.000^{1-\alpha}$	2030	49.01%	2121	42.01%	1.0449
$\{\eta_t\}_{t=2020}^{2044} = 1.015^{1-\alpha}$	2030	47.01%	2103	42.01%	1.1097
$\{\eta_t\}_{t=2020}^{2044} = 1.020^{1-\alpha}$	2030	46.01%	2095	42.01%	1.1304
$\{\eta_t\}_{t=2016}^{\infty} = 1.020^{1-\alpha}$	2044	21.45%	2116	12.45%	1.1874

In the last row, we allow the economic growth rates to rise from 1.1% to 2% permanently for 2016. As the permanent higher balanced growth rate leads to an increase in the tax base, the government revenue and expenditure tend to be more balanced, and as a result, the government does not need to increase much consumption tax rate during the transition period and the steady-state, compared with Experiment 2. Thus, the values of τ_{c,T_1} and τ_{c,T_2} are much lower in the last case than those in Experiment 2.

2.5.4 Welfare Analysis

In this subsection, we explore the impact of fiscal policy on the household's welfare in each experiment. According to consumer welfare theory, welfare is gained when the household's utility increases, whereas welfare is lost when the household's utility reduces. The point is how to measure the change in welfare. As utility is ordinal, we can not directly use the difference of utility to measure it. In our analysis, we follow the measurement of Cooley and Hansen (1991, 1992) and Hansen and Imrohoroglu (2016) who use the consumption equivalent variation to measure the change in welfare. This measurement works as follows: We adjust the consumption within the utility function in Experiment 2 by $(1+\lambda)$ such that the present discounted utility function in Experiment 2 is equal to that in another experiment.

To be more specific, Equation (2.31) shows the present utility function in Experiment 2 and we denote it as $\widehat{W}$. $\widehat{C}_t$, $\widehat{h}_t$, and $\widehat{B}_{t+1}$ are the consumption, hours, and government bonds in Experiment 2.

$$\widehat{W} = \sum_{t=1995}^{\infty} \beta^t N_t \left[log\widehat{C}_t - \rho \frac{\widehat{h}_t^{1+1/\phi}}{1+1/\phi} + \theta log(\mu_t + \widehat{B}_{t+1}) \right] \tag{2.31}$$

W in Equation (2.32) is the utility associated with one of the other fiscal policies. Now we adjust $\widehat{C}_t$ in Equation (2.31) by $(1+\lambda)$ in each period so that the adjusted utility in Experiment 2 equals to W. In other words, the percentage increase in consumption λ must hold Equation (2.32) true.

$$W = \sum_{t=1995}^{\infty} \beta^t N_t \left[log(1+\lambda)\widehat{C}_t - \rho \frac{\widehat{h}_t^{1+1/\phi}}{1+1/\phi} + \theta log(\mu_t + \widehat{B}_{t+1}) \right] \tag{2.32}$$

Solving for λ yields

$$\lambda = \exp\left(\frac{W - \widehat{W}}{\sum_{t=1995}^{\infty} \beta^t N_t}\right) - 1 \tag{2.33}$$

Table 2.8 shows the welfare cost as a percentage change in consumption associated with different experiments. The results indicate several points: First, compared the value of λ in Experiment 3 with that in Experiment 1, we can see that the welfare cost relative to Experiment 2 is higher when using labor income tax to finance the expenditures than using consumption income tax. Second, recall that in Experiments 1 and 3, the distorting tax rate is the only fiscal instrument to increase the tax revenue, whereas Experiments 2 and 4 also consider the tax broadening as an additional instrument to pay for the projected government expenditures. The results shown in Table 2.8 indicate that the household benefits from tax base broadening, with the welfare cost in Experiment 1 being 0.72% greater than in Experiment 2, and the relative welfare cost in Experiment 4 being greater than in Experiment 3. Finally, we also calculate the welfare changes in the experiments described in Section 2.5.3 where we experiment with different debt to output ratios for Experiment 2. The penultimate row shows that the household can gain welfare of 0.15% when we assume a higher steady-state level of debt to output ratio (100%) and keep the maximum debt to output ratio (200%) unchanged in Experiment 2. By doing so, the government does not need to raise much revenue to reach a lower steady-state level of debt to output ratio. Hence we obtain a lower consumption tax rate during the transition period. However, as a higher debt in the steady state and a higher consumption tax rate are required to finance it, we obtain a higher consumption tax rate in the steady-state. This result indicates that in the case of Experiment 2, the household prefers lower taxes during the transfer period, even it faces a higher tax in the steady state. The last row is the case that we assume a lower value of br_{max} (150%) but a slightly higher value of br^* (80%) in Experiment 2. Recall that by doing this, both consumption tax rates during the transition period and in a steady state are higher than those in Experiment 2, leading to the welfare cost of 0.54% in this case relative to Experiment 2.

Table 2.8: Welfare analysis: consumption equivalent variation (λ) relative to Experiment 2

Experiment 1	-0.72%
Experiment 3	-18.43%
Experiment 4	-16.43%
$br_{max} = 2.0$	+0.15%
$br^* = 1.0$	
$br_{max} = 1.5$	-0.54%
$br^* = 0.8$	

2.6 Conclusion

The UK government is facing a significant fiscal burden reflected by a high government debt to output ratio. In addition, the UK's government expenditures such as public spending on public pensions, health, and social care are projected to increase due to the population aging in the UK, implying that the debt to output ratio will continue to rise in the future. It is reasonable for the UK government to stabilize the debt and restore the fiscal balance when the government debt relative to output increases to an unsustainable high level.

This paper uses a Neoclassical growth model combined with a debt sustainability rule to measure the additional tax revenues and tax rates needed to pay for the future government expenditures and at the same time stabilize government debt to output ratio to 60%. In particular, the benchmark experiment uses lump-sum tax to finance the projected increase in government expenditures and stabilize the debt. We also explore the fiscal reforms by increasing the consumption tax rate or labor income tax rate to achieve fiscal stability.

The main result is that the revenue needed to finance the future government expenditures and stabilize the debt to output ratio to 60% in the steady state is in the range of 20-24% of consumption expenditures. When a distorting tax such as consumption tax or labor income tax is used to achieve the goal, the tax rate must be set to a high level. Specifically, the consumption tax rate needs to increase to above 50%, whereas the labor income tax rate has to rise to over 70%. Even if the government is allowed to consider the tax base broadening, the distorting tax rates are still required to increase to the level of 45%-60%. Also, although both consumption and labor income tax rates distort labor supply, the consumption tax is less distorting than the labor income tax.

Such high levels of the tax rates indicate that using the consumption tax rate or labor income tax rate is not a feasible fiscal policy for the UK government to raise the revenue and mitigate the fiscal burden in the future. This result brings us to find other ways to reduce the fiscal pressures in the UK. For example, instead of increasing tax revenue, the government can cut its expenditures. The UK government has taken some actions to cut government expenditures: In 2015, the government announced cutting working-age welfare spending.[11] The fiscal burden in the UK is mainly from an increase in health spending due to the problem of the aging population. Therefore, the UK government still needs to reduce the relevant spending by reforming the pension system. Other ways to mitigate the fiscal burden may include increasing the economic growth rate by improving the technology and innovation and increasing the number of working-age people relative to the number of the old-age population, such as reforming the immigration policies and family policies. The feasible policies to mitigate the financial burden in the UK are left for future research.

[11]This includes "cuts to the universal credit and 4-year cash freeze in uprating most tax credits and benefits of the working-age population" (OBR, 2017).

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Appendix

A1 The derivation of the household's problem

This appendix provides details of derivation of household's problem. Household is maximizing utility subject to its budget constraint. Therefore, combine equation (2.2) with equation (2.3) and the Lagrangian function is as the following equation:

$$\mathscr{L} = \sum_{t=0}^{\infty}\beta^t N_t \left[logC_t - \rho\frac{h_t^{1+1/\phi}}{1+1/\phi} + \theta log(\mu_t + B_{t+1})\right] + \sum_{t=0}^{\infty}\beta^t\lambda_t\{(1-\tau_{l,t})W_t h_t + [1+ (1-\tau_{k,t})(r_t-\delta)]K_t + [1-(1-q_{t-1})\tau_{b,t}]B_t + T_t - (1+\tau_{c,t})C_t - \Omega_t K_{t+1} - q_t\Omega_t B_{t+1}\} \tag{34}$$

where λ_t is Lagrange multiplier. The first-order conditions are as follows:

$$\frac{\partial\mathscr{L}}{\partial C_t} = \frac{\beta^t N_t}{C_t} - \beta^t\lambda_t(1+\tau_{c,t}) = 0 \Rightarrow C_t = \frac{N_t}{\lambda_t(1+\tau_{c,t})} \tag{35}$$

$$\begin{aligned}\frac{\partial\mathscr{L}}{\partial K_{t+1}} &= -\beta^t\lambda_t\Omega_t + \beta^{t+1}\lambda_{t+1}[1+(1-\tau_{k,t+1})(r_{t+1}-\delta)] = 0\\ \Rightarrow \lambda_t\Omega_t &= \beta\lambda_{t+1}[1+(1-\tau_{k,t+1})(r_{t+1}-\delta)]\end{aligned} \tag{36}$$

$$\begin{aligned}\frac{\partial\mathscr{L}}{\partial B_{t+1}} &= \frac{\beta^t N_t\theta}{\mu_t + B_{t+1}} - \beta^t\lambda_t q_t\Omega_t + \beta^{t+1}\lambda_{t+1}[1-(1-q_t)\tau_{b,t+1}] = 0\\ \Rightarrow \frac{N_t\theta}{\mu_t+B_{t+1}} - \lambda_t q_t\Omega_t &= -\beta\lambda_{t+1}[1-(1-q_t)\tau_{b,t+1}]\end{aligned} \tag{37}$$

$$\begin{aligned}\frac{\partial\mathscr{L}}{\partial h_t} &= -N_t\rho h_t^{1/\phi} + \lambda_t[(1-\tau_{l,t})W_t] = 0\\ \Rightarrow N_t\rho h_t^{1/\phi} &= \lambda_t[(1-\tau_{l,t})W_t]\end{aligned} \tag{38}$$

A2 The derivation of detrended equilibrium conditions

In this appendix we derive the detrended equilibrium conditions to use in solving the model numerically. Given a trending per capita variable J_t we obtain its detrended per capita counterpart by using Equation (2.10).

Using equations (2.1), (2.6), (2.10), (35), and (36), the detrended Euler equation (dynamic optimality condition for consumption) can be derived using the following process:

$$
\begin{aligned}
\frac{C_{t+1}}{C_t} =& \frac{\lambda_{t+1}(1+\tau_{c,t+1})N_t}{N_{t+1}\lambda_t(1+\tau_{c,t})} = \frac{\Omega_t}{\beta[1+(1-\tau_{k,t+1})(r_{t+1}-\delta)](1+\tau_{c,t})} \cdot \frac{(1+\tau_{c,t+1})N_t}{(1+\tau_{c,t})N_{t+1}} \\
\Rightarrow& \frac{A_{t+1}^{1/(1-\alpha)} c_{t+1}}{A_t^{1/(1-\alpha)} c_t} = \frac{1}{\beta[1+(1-\tau_{k,t+1})(r_{t+1}-\delta)](1+\tau_{c,t})} \cdot \frac{(1+\tau_{c,t+1})}{(1+\tau_{c,t})} \\
\Rightarrow& \frac{(1+\tau_{c,t+1})\eta_t^{1/(1-\alpha)} c_{t+1}}{(1+\tau_{c,t})c_t} = \beta[1+(1-\tau_{k,t+1})(r_{t+1}-\delta)]
\end{aligned} \tag{39}
$$

The detrended bond Euler equation (dynamic optimality condition for bond) can be derived from equations (2.1), (2.6), (2.10), (35), and (37):

$$
\begin{aligned}
& \frac{N_t\theta}{\mu_t+B_{t+1}} - \frac{q_t\Omega_t N_t}{C_t(1+\tau_{c,t})} = -\beta[1-(1-q_t)\tau_{b,t+1}]\frac{N_{t+1}}{C_{t+1}(1+\tau_{c,t+1})} \\
\Rightarrow & \frac{\theta}{\mu_t+B_{t+1}} - \frac{q_t\Omega_t}{C_t(1+\tau_{c,t})} = -\beta[1-(1-q_t)\tau_{b,t+1}]\frac{\Omega_t}{C_{t+1}(1+\tau_{c,t+1})} \\
\Rightarrow & \frac{\theta}{\mu_t+A_{t+1}^{1/(1-\alpha)}b_{t+1}} - \frac{q_t\Omega_t}{A_t^{1/(1-\alpha)}c_t(1+\tau_{c,t})} = \\
& -\beta[1-(1-q_t)\tau_{b,t+1}]\frac{\Omega_t}{A_{t+1}^{1/(1-\alpha)}c_{t+1}(1+\tau_{c,t+1})} \\
\Rightarrow & \frac{\theta}{\mu_t+\gamma_t^{1/(1-\alpha)}b_{t+1}} - \frac{q_t\Omega_t}{c_t(1+\tau_{c,t})} = \\
& -\beta[1-(1-q_t)\tau_{b,t+1}]\frac{\Omega_t}{\gamma_t^{1/(1-\alpha)}c_{t+1}(1+\tau_{c,t+1})} \\
\Rightarrow & \frac{\theta}{\mu_t+b_{t+1}} + \beta[1-(1-q_t)\tau_{b,t+1}]\frac{\Omega_t}{c_{t+1}(1+\tau_{c,t+1})} = \frac{q_t\eta_t^{1/(1-\alpha)}}{c_t(1+\tau_{c,t})}
\end{aligned} \tag{40}
$$

Using equations (2.10), (35), and (38), we could derive the detrended first order condition for hours worked which is shown in Equation (41):

$$
N_t\rho h_t^{1/\phi} = \frac{N_t}{C_t(1+\tau_{c,t})} \cdot [(1-\tau_{h,t})W_t \Rightarrow \rho h_t^{1/\phi} = \frac{[(1-\tau_{h,t})w_t}{c_t(1+\tau_{c,t})} \tag{41}
$$

We obtain the detrended production function by using equations (2.4), (2.6), and

(2.10):

$$A_t^{1/(1-\alpha)} y_t = A_t \cdot (A_t^{1/(1-\alpha)} k_t)^{\alpha} \cdot h_t^{1/(1-\alpha)} \Rightarrow y_t = k_t^{\alpha} \cdot h_t^{1/(1-\alpha)} \tag{42}$$

The fifth detrended equation is for the law of motion of capital which can be derived using equations (2.5), (2.6), and (2.10):

$$\begin{aligned} \Omega_t A_{t+1}^{1/(1-\alpha)} k_{t+1} =&(1-\delta) A_t^{1/(1-\alpha)} k_t + A_t^{1/(1-\alpha)} x_t \\ \Rightarrow \Omega_t \gamma_t^{1/(1-\alpha)} k_{t+1} =&(1-\delta) k_t + x_t \end{aligned} \tag{43}$$

The following process can be used to derive the detrended budget constraint for the household from equation (2.3), (2.6), and (2.10):

$$\begin{aligned} &(1+\tau_{c,t})c_t + \Omega_t \gamma_t^{1/(1-\alpha)} k_{t+1} + q_t \Omega_t \gamma_t^{1/(1-\alpha)} b_{t+1} \\ &= (1-\tau_{h,t}) w_t h_t + [1+(1-\tau_{k,t})(r_t-\delta)]k_t + [1-(1-q_{t-1})\tau_{b,t}]b_t + tr_t - d_t \end{aligned} \tag{44}$$

Equation (45) expresses the detrended government budget constraint which is obtained from equations (2.6), (2.7), and (2.10):

$$\begin{aligned} g_t + tr_t + b_t = &\, q_t \Omega_t \gamma_t^{1/(1-\alpha)} b_{t+1} + \tau_{c,t} c_t \\ &+ \tau_{h,t} w_t h_t + \tau_{k,t}(r_t-\delta) k_t + \tau_{b,t}(1-q_{t-1}) b_t + d_t \end{aligned} \tag{45}$$

The detrended debt sustainability rule can be derived using Equation (2.8) and Equation (2.10), can shown in the following equation:

$$d_t = \begin{cases} \kappa(b_t - \bar{b}\bar{y}) & \text{if } b_s/y_s \geq b_{max} \text{ for some } s \leq t, \\ 0 & \text{otherwise} \end{cases} \tag{46}$$

where $\bar{y}$ is the value of y_t along the balanced growth path and $\bar{b}$ is the targeted debt to output ratio along the balanced growth path.

Finally, using equations (2.6), (2.10), and equations in Section 2.2.4, the detrended market clearing conditions can be expressed using the following equations:

$$w_t = (1-\alpha)k_t^{\alpha}h_t^{-\alpha} \quad (47)$$

$$r_t = \alpha k_t^{\alpha-1}h_t^{1-\alpha} \quad (48)$$

$$c_t + x_t + g_t = y_t \quad (49)$$

A3 The derivation of steady-state equilibrium conditions

This appendix provides details of derivation on steady state (Long-Run) equilibrium.

The steady state ratio of government $\frac{g^*}{y^*}$ and $\frac{b^*}{y^*}$ are given, let variable with star be the steady state.

The steady state of capital to output ratio [from equations (39), (42), and (48)]:

$$\begin{aligned}
[42] \Rightarrow & \frac{k_t}{y_t} = 1/k_t^{\alpha-1}h_t^{1-\alpha} \\
[48] \Rightarrow & \frac{k_t}{y_t} = \frac{\alpha}{r_t} \\
[39] \Rightarrow & \frac{(1+\tau_c)\gamma^{1/(1-\alpha)}c^*}{(1+\tau_c)c^*} = \beta[1+(1-\tau_k)(r^*-\delta)] \\
\Rightarrow & r^* = \frac{\gamma^{1/(1-\alpha)}-\beta}{\beta(1-\tau_k)} + \delta \\
\frac{k^*}{y^*} = & \frac{\alpha}{\frac{\gamma^{1/(1-\alpha)}-\beta}{\beta(1-\tau_k)} + \delta} = \frac{\alpha(1-\tau_k)}{\frac{\gamma^{1/(1-\alpha)}}{\beta} - 1 + \delta(1-\tau_k)}
\end{aligned} \quad (50)$$

The steady state of investment to output ratio [from Equation (43)]:

$$\begin{aligned}
[43] \Rightarrow & \Omega\gamma^{1/(1-\alpha)}k^* = (1-\delta)k^* + x^* \\
\frac{x^*}{y^*} = & (\delta - 1 + \eta\gamma^{1/(1-\alpha)})\frac{k^*}{y^*}
\end{aligned} \quad (51)$$

The steady state of consumption to output ratio [from Equation (49)]:

$$\frac{c^*}{y^*} = 1 - \frac{g^*}{y^*} - \frac{x^*}{y^*} \quad (52)$$

The steady state of working hours [from equations (41), (42), (47)]:

$$
\begin{aligned}
[41][47] \Rightarrow & \rho h^{*1/\phi} = \frac{(1-\tau_h)w^*}{c^*(1+\tau_c)} = \frac{(1-\tau_h)(1-\alpha)k^{*\alpha}h^{*-\alpha}}{c^*(1+\tau_c)} \\
[42] \Rightarrow & \rho h^{*1/\phi} = \frac{(1-\tau_h)(1-\alpha)y^*h^{*\alpha-1}h^{*-\alpha}}{c^*(1+\tau_c)} \\
h^* = & [\frac{(1-\tau_h)(1-\alpha)}{\rho(1+\tau_c)\frac{c^*}{y^*}}]^{\phi/(1+\phi)}
\end{aligned}
\tag{53}
$$

The steady state of output [from (42)]:

$$
y^* = k^{*\alpha} \cdot h^{*1/(1-\alpha)} \tag{54}
$$

The steady state of price of bond [from (40)]:

$$
\begin{aligned}
\frac{\beta\Omega\tau_b q^*}{c^*(1+\tau_c)} - \frac{\Omega\gamma^{1/(1-\alpha)}q^*}{c^*(1+\tau_c)} = & -\frac{\theta}{\mu+b^*} + \beta[1-\tau_b]\frac{\Omega}{c^*(1+\tau_c)} \\
q^* = & \frac{\theta(1+\tau_c)c^* + \beta(1-\tau_b)\Omega(\mu+b^*)}{(\gamma^{1/(1-\alpha)}-\beta\tau_b)\Omega(\mu+b^*)} \\
q^* = & \frac{\theta(1+\tau_c)\frac{c^*}{y^*} + \beta(1-\tau_b)\Omega(\frac{\mu}{y^*}+\frac{b^*}{y^*})}{\Omega(\gamma^{1/(1-\theta)}-\beta\tau_b)(\frac{\mu}{y^*}+\frac{b^*}{y^*})}
\end{aligned}
\tag{55}
$$

According to the debt sustainability rule, debt reduction is zero in the steady state (i.e., $d^* = 0$), thus using equations (42), (45), and (47), the steady state of transfer payments to output ratio can be expressed as the following equation:

$$
\begin{aligned}
& \frac{g^*}{y^*} + \frac{tr^*}{y^*} + \frac{b^*}{y^*} = q^*\eta\Omega\gamma\frac{b^*}{y^*} + \tau_c\frac{c^*}{y^*} + \tau_h\frac{w^*h^*}{y^*} + \tau_k(r^*-\delta)\frac{k^*}{y^*} + \tau_b(1-q^*)\frac{b^*}{y^*} \\
\Rightarrow & \frac{tr^*}{y^*} = [q^*\Omega\gamma^{1/(1-\alpha)} + \tau_b(1-q^*) - 1]\frac{b^*}{y^*} + \tau_c\frac{c^*}{y^*} + \tau_k(r^*-\delta)\frac{k^*}{y^*} + \tau_h(1-\alpha) - \frac{g^*}{y^*}
\end{aligned}
\tag{56}
$$

The steady state of consumption:

$$
c^* = \frac{c^*}{y^*} \cdot y^* \tag{57}
$$

The steady state of government consumption:

$$g^* = \frac{g^*}{y^*} \cdot y^* \tag{58}$$

The steady state of wages [from (42), (47)]:

$$w^* = \frac{(1-\alpha)y^*}{h^*} \tag{59}$$

The steady state of interest rate [from (42), (43)]:

$$r^* = \alpha k^{*\alpha-1} h^{*1-\alpha} = \alpha / (\frac{k^*}{y^*}) \tag{60}$$

The steady state of investment:

$$x^* = \frac{x^*}{y^*} \cdot y^* \tag{61}$$

The steady state of government bonds:

$$b^* = \frac{b^*}{y^*} \cdot y^* \tag{62}$$

The steady state of transfer payment:

$$tr^* = \frac{tr^*}{y^*} \cdot y^* \tag{63}$$

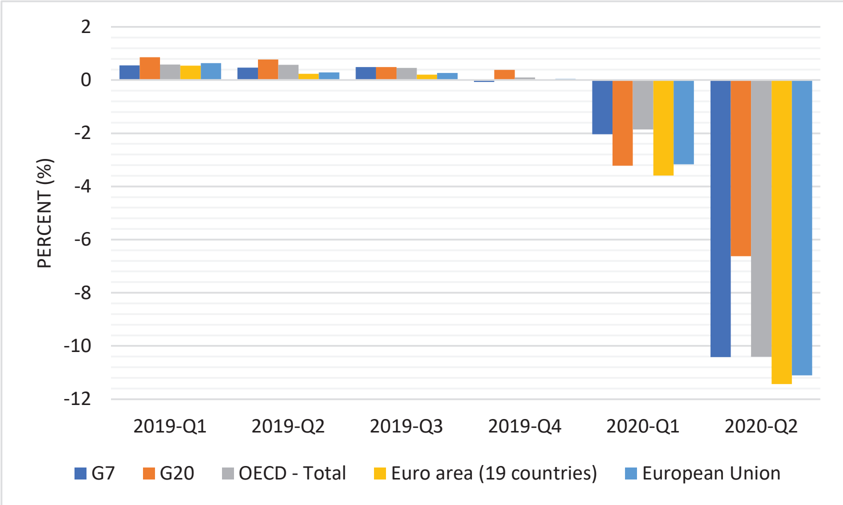
Chapter 3

The Effectiveness of Public Investment: The Role of Public Debt Sustainability

3.1 Introduction

The ongoing global outbreak of coronavirus pandemic 2019 (COVID-19) continues to be an unprecedented crisis with wide-ranging repercussions on global economic growth. Figure 3.1 shows that major economies' gross domestic product (GDP) in the first quarter of 2020 drops significantly from the previous quarter. These countries suffer an even worse recession in the second quarter. Governments across the world are seeking the right policies to recover economic activities. Under such circumstances, there is a growing interest in the effect of public investment on boosting the economy and the effectiveness of public investment multipliers. The British government, for instance, has announced £600 billion plans on infrastructure to support jobs and boost the economy for the post-COVID-19 period (HM Treasury, 2021).

Public investment is crucial for economic growth, boosting productivity and competitiveness (e.g., Krugman, 2016; Aschauer, 1989; Baxter and King, 1993). Although there is a wide discussion on the positive impact of Public investment on Economic Growth, the size of public investment multipliers has not been fully explored due to limitations of data availability and identification methods. Our research contributes to the existing literature on fiscal multipliers by identifying the size of public investment multipliers for 14 members of the OECD over the 1985-2018 period.



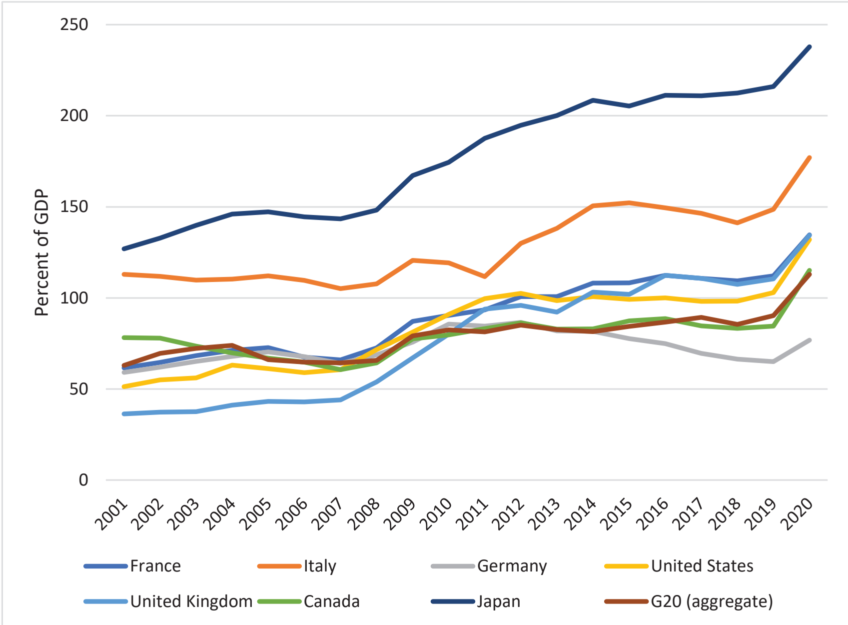
Source: OECD Quarterly National Accounts Database.

Figure 3.1: Quarterly GDP in volume terms

(Percentage change on the previous quarter, seasonally adjusted)

Also, the public debt levels in many countries have been at a high level before the pandemic. They will reach a new record to support the health system, protect people's lives, and provide financial assistance to vulnerable households and small firms. Figure 3.2 shows the ratios of general government debt to GDP for the G7 countries across 2007-20. All countries have witnessed an increase in their debt-to-GDP ratio. The growth has been reasonably dramatic since 2019.

The sustainability of public debt can have an impact on the effectiveness of public investment through two channels: (i) Consumers in an economy with a high level of public debt would anticipate a rise in taxation to pay for the excessive public debt, creating an incentive to save more and consume less following a public investment shock. As a result, the stimulative effect of public investment on aggregate demand is diminished. This behavior is referred to as Ricardian equivalence. (ii) Sizable public debt could raise the sovereign credit risk, which in turn pushes up the borrowing costs of the whole economy, and thus undermines the effectiveness of public investment on stimulating aggregate demand (Corsetti et al., 2013). Both theories imply that public investment is less effective when the public debt is unsustainable. However, there is a lack of systematic empirical analysis of this perspective in the existing literature.



Source: BIS Credit to the Non-Financial Sector Database.

Figure 3.2: General government debt as a percentage of GDP, G-7 countries

To address this question, this chapter contributes to the literature by investigating how and through which channels the public debt sustainability may affect the effectiveness of public investment. To be specific, the debt-to-GDP ratio is used to measure the state of fiscal sustainability. The weak-debt state is defined as a state where the debt-to-GDP ratio exceeds a specific high level, whereas the strong-debt state is where the public debt ratio stays relatively low. We then study the effect of a public investment shock on output depending on these two debt states. This study also examine if the response of private consumption to a public investment shock is smaller in a weak-debt state than in a strong-debt state (Ricardian equivalence channel) and if the response of borrowing costs is stronger in response to growing concerns about the sovereign risk when an economy in a weak-debt state increases public investment to stimulate the economy (sovereign risk channel). The following are the main findings in this chapter:

- The increased public investment raises output in the short term, with a maximum public investment multiplier of 3.7 and an average public investment multiplier of about 2.3 over three years.

- The effects vary with the different public debt regimes. An increase in public investment could have a bigger effect on output in a strong-debt state than in a weak-debt state.

- The public debt sustainability can affect the effectiveness of public investment through two channels: Ricardian equivalence channel and sovereign risk channel.

The rest of the paper is structured as follows. Section 3.2 provides a literature review. Section 3.3 discusses the data and empirical strategy. Section 3.4 reviews and comments on the empirical results. Section 3.5 presents some robustness tests. Section 3.6 concludes.

3.2 Literature review

This section summarises the existing literature on strategies for identifying government spending shocks and the relationship between the effectiveness of fiscal policy and public debt sustainability.

3.2.1 The identification strategies of government spending shocks

Our paper contributes to a broad range of empirical literature that evaluates the economic effects of changes in government spending. There are three primary methods for identifying government spending shocks.

(i) The narrative approach, which is the method of using fluctuations in military build-ups to identify the exogenous government spending shocks in the United States. This strategy was first introduced in Barro (1981) and refined by Ramey and Shapiro (1999).[1] Other examples where this approach has been applied include: Ramey and Shapiro (1999); Hall (2009); Fisher and Peters (2010); Ramey (2011b); Barro and Redlick (2011) and Nakamura and Steinsson (2014). A common shortcoming of the narrative approach is that it relies on the presumption that the multiplier is identical across all types of government spending. However, it is reasonable to believe that the

[1] Barro (1981) argues that the narrative approach works in light of the fact that the major conflicts occurred outside the United States and were determined by geopolitical factors that have no direct effect on the US economy; consequently, the shocks identified using this approach are exogenous.

causal impacts on output vary according to the different components of government spending. For instance, Baxter and King (1993) build a neoclassical model demonstrating that within government purchases, the government investment multiplier is larger than the government consumption multiplier since government consumption is treated as nonproductive in the model whereas government investment is productive.

(ii) The vector autoregression (VAR) approach was the first employed in the empirical analysis of fiscal policy by Blanchard and Perotti (2002). This approach bases on the quarterly data and the assumption that changes in government spending cannot respond to the contemporaneous economy within a quarter. It orders the government spending first in a VAR model and identifies the government spending shock as the Cholesky innovation to government spending. Other studies that have used this approach include Galí et al. (2007), Perotti et al. (2008), and Mountford and Uhlig (2009). However, Ramey (2011b), Leeper et al. (2012, 2013), and Forni and Gambetti (2010) challenge this approach by arguing that the VAR shocks fail to capture the timing of news due to the role of "fiscal foresight". That is, private agents anticipate fiscal consolidation before it actually takes place. In turn, private agents adjust their consumption and investment behavior based on their anticipation, making the government spending shocks and the related impulse response functions highly implausible.

(iii) The forecast error approach was initially applied to identify government spending shocks by Auerbach and Gorodnichenko (2012). They define the forecast error of government spending as the difference between the actual and forecast government spending growth rates and proxy it as unanticipated government spending shocks. The effects of government spending shocks are measured using the local projection method of Jordà (2005). By employing this method to a large number of OECD countries using semi-annual data, Auerbach and Gorodnichenko (2013) discovered that the government purchase multiplier is greater in recession than in expansion. The forecast error approach overcomes the shortcomings of the two approaches mentioned above. First, the forecast error has omitted all anticipated news by subtracting the forecast government spending from the actual government spending. As a result, it eliminates the "fiscal foresight" problem. Second, this approach can be used to identify different types of government spending shocks as long as the actual and projected data on the components of government spending are available. Fortunately, the OECD projects the economy and publishes the forecasts for key macroeconomic variables (e.g., GDP, government consumption, and public investment) in its Economic Outlook (EO) database twice each year, enabling researchers to conduct further studies on the short-run stimulative effects of the decomposition of government spending. Due to the advantages of this approach on fiscal shock identification, several studies have applied it to identify fiscal shocks. Table 3.1 summarizes details of existing literature using the above three identification approaches.

The prevailing literature has been carried out on the causal effect of government purchases, defined as the sum of government consumption and investment. However, there is a general lack of research on the public investment multiplier.

The existing literature studying the effects of public investment includes Kamps (2005) who use a VAR model to examine the effect of public investment shocks on other macroeconomic variables for 22 OECD countries. While they find positive effects of public investment on output, the identification method to measure the public investment shock is implausible because the study uses annual data. As a result, the estimated public investment shocks may include the endogenous responses to other macroeconomic shocks. Researches examining the effect of pubic investment shocks using a VAR model based on quarterly data include Otto and Voss (1996) and Mittnik and Neumann (2001). Both of them find a positive effect of public investment on output. In contrast, Perotti (2004) find an evidence on crowding-out effect. Despite the ambiguous results, of greater concern is that the government investment shock they identified consists of both anticipated and unanticipated information; thus, the problem of "fiscal foresight" cannot be eliminated.

Table 3.1: Summary of the size of government spending multipliers

Study	Approach	Identification	Multiplier
Barro (1981); Hall (2009); Barro and Redlick (2011)	Narrative Approach	Use military spending as instrument for government spending	neoclassical effects
Ramey and Shapiro (1999); Edelberg et al. (1999); Burnside et al. (2004); Cavallo (2005); Eichenbaum and Fisher (2005),	Narrative Approach	Focus on changes in military buildups associated with Ramey-Shapiro episodes, which are three war periods, arguably uncorrelated with other contemporaneous economic shocks	neoclassical effects
Ramey (2011a)	Narrative Approach	Based on U.S. deficit-financed increase in government purchases caused by military events, based on narrative evidence	neoclassical effects
Fisher and Peters (2010)	Narrative Approach	Use excess stock returns of military contractors to identify shocks	neoclassical effects
Blanchard and Perotti (2002); Galí et al. (2007)	SVAR Approach	Choleski decomposition with G ordered first	Keynesian effects
Perotti et al. (2008)	VAR Approach	Estimate multiple variations over different time periods and countries (U.S., Australia, Canada and the United Kingdom)	Keynesian effects
Mountford and Uhlig (2009)	VAR Approach	Use sign restrictions to identify government spending shock	consumption does not fall while real wages do not rise
Auerbach and Gorodnichenko (2012, 2013); Blanchard and Leigh (2013); Abdul et al. (2016); Belinga and Ngouana (2015); Riera et al. (2014); Riera-Crichton et al. (2015)	Forecast Error	government spending shock is defined as the forecast error of government spending which is the difference between the actual and forecast government spending	fiscal multipliers vary according to the state of the economy.

This chapter employs the forecast error approach and identifies the exogenous public investment shocks as the forecast error of public investment relative to output. As indicated above, this strategy is capable of resolving the issue of "fiscal foresight". The most relevant to our analysis is Abdul et al. (2016), which use the forecast errors of public investment to identify the public investment shock for 17 OECD economies for 1985-13 and find that the public investment multiplier is about 1.4 in the medium term. Unlike the identification method in Abdul et al. (2016), which utilises data with an annual frequency, our research employs data with a high frequency (semiannual data). To improve the identification of fiscal shocks, high-frequency data is preferred to be employed in studies that estimate the macroeconomic responses to fiscal shocks. In contrast, when we compared the results with those of Abdul et al. (2016), we found that our results are consistent with the public investment multiplier estimated by Abdul et al. (2016). Nevertheless, Abdul et al. (2016) did not take into account the effect of public debt sustainability on the effectiveness of public investment. As indicated below, public debt sustainability could affect the effectiveness of fiscal policies. With a high debt-to-output ratio, the efficacy of public investment may decline. Therefore, the public investment multiplier may become implausible without considering the effect of public debt sustainability. Our research contributes to the literature by exploring how and through which channels the sustainability of public debt might affect the effectiveness of public investment.

3.2.2 Fiscal policy effectiveness and public debt sustainability

Academics have recently given increasing attention to the issue of rising government debt. Many researchers (e.g., Chung and Leeper, 2007; Favero and Giavazzi, 2007; Corsetti et al., 2012; Favero et al., 2011) have pointed out that excluding government debt from the model as an endogenous variable or ignoring debt dynamics might result in significant biases because the response of public debt to government spending is not taken into account. The state of public debt can harm economic growth. For instance, Reinhart and Rogoff (2010) examine the effect of public debt sustainability on the economic growth for 44 countries over 200 years, and the result shows that the economic growth is lower when the debt-to-GDP ratio exceeds 90%. According to the study for 18 OECD countries by Cecchetti et al. (2011), the public debt accumulation hurts the

GDP growth when the debt-to-GDP ratio is in the range of 80% and 100%. Furthermore, a similar threshold of 90% to 100% is found by Checherita and Rother (2012) for analyzing the relationship between public debt sustainability and economic growth for 12 European countries.

Public debt sustainability may also affect the effectiveness of fiscal policies through two channels. One channel is based on the Ricardian equivalence. That is, the private agents cut down consumption today and increase the precautionary saving in anticipating a tax hike in the future to pay off the increased government debt (Ricardo, 1912). While Keynesianism indicates that expansionary fiscal policy can effectively boost the economy in the short run, such effectiveness may diminish when the debt-to-GDP ratio is too high. Perotti (1999) and Sutherland (1997) demonstrate that whereas fiscal policy has Keynesian effects on private consumption at low levels of public debt, it has contractionary impacts at high levels of public debt. Giavazzi and Pagano (1990, 1995) find that the fiscal policy changes can have non-Keynesian effects on private consumption in cases of Denmark, Ireland, Sweden, and also 19 OECD countries, when the role of the expectation is taken into consideration. In particular, Giavazzi and Pagano (1990) claim that the expectation of tax cuts in the future due to a reduction in government spending can explain the surprisingly high private consumption levels in Ireland and Denmark in the late 1980s. On the other hand, Giavazzi and Pagano (1995) point out that the drop in private consumption in Sweden may result from the anticipation of the private sector in higher future tax burden because of the fiscal expansion. By examining the effect of government spending shocks at different levels of the public debt ratio for 17 Euro area countries, Nickel and Tudyka (2014) provide evidence in favor of Ricardian equivalence. Huidrom et al. (2020) also find a negative effect of government consumption shocks on private consumption in a weak fiscal position.

Investor's expectation of sovereign credit risk can also affect the effectiveness of fiscal policies. Corsetti et al. (2013) build a dynamic stochastic general equilibrium (DSGE) model to provide a formal examination of the sovereign risk channel. They find that sizable public debts could raise the sovereign credit risk, which in turn pushes up the borrowing costs of the whole economy, and thus undermines the effectiveness of fiscal policies on stimulating aggregate demand. Auerbach and Gorodnichenko (2017) are the pioneers of empirical research on the sovereign risk channel. They employ a cross-country data set for 17 OECD countries and find that the effect of government spending shocks varies according to different levels of public debt. However, the magnitude is negligible. Also, they cannot find evidence for the sovereign risk channel in their study. One reason for this failure may be because they define the debt state by focusing on within-country variation in debt and thus ignore all cross-country variation in pubic debt. In contrast, Huidrom et al. (2020) show a rise in Credit Default Swaps (CDS) spreads following a positive government consumption shock when public debt is high, which supports the sovereign risk consideration.

The existing literature has not conducted a systematic analysis of the impact of public debt sustainability on the effectiveness of public investment. We contribute to the literature by studying this mechanism and exploring if this mechanism works through the two channels discussed earlier: Ricardian equivalence and sovereign risk.

3.3 Data and methodology

Following the identification approach applied in Auerbach and Gorodnichenko (2012, 2013) and Abdul et al. (2016), the empirical analysis in this chapter uses the forecast error to identify the unanticipated shock. The local projection method is employed to estimate short-run effects of public investment shocks on macroeconomic aggregates for 14 OECD member countries over 1985-2018.[2] This section summarises the data and methodology used in this chapter. Table 3.2 and Table 3.3 report the data availability and descriptive statistics for key macroeconomic variables.

3.3.1 Data

Forecasts of Public investment: Forecast data of public investment to GDP comes from the OECD EO database. The OECD forecasts the major economic trends and prospects for its members and some non-member countries in each spring and fall and releases projections of major macroeconomic variables in the context of the OECD EO. The OECD projections have been examined and evaluated regularly and are considered to be performing better than average (Lenain, 2002; Vogel, 2007).

[2]The 14 countries covered are Australia, Belgium, Canada, Denmark, Finland, France, Germany, Japan, Netherlands, New Zealand, Norway, Sweden, United Kingdom, United States.

We collect the forecast data using the EO database from No. 38 to No.104, which covers the forecast data for the second half of 1985 until the second half of 2018. The public investment as a share of GDP is computed using the series of government gross fixed capital formation (volume, market prices, OECD CODE: IGV), divided by the series of real GDP (volume, market prices, OECD CODE: GDPV). As the base year is different for each country and each volume of the EO, I re-scale the series to the same base year and convert data into constant 2015 using the relevant deflators. Forecast data are available at quarter-frequency in the EO database from No. 73 to No. 104, but only available at semi-annual frequency prior to EO No.73. Therefore, we convert the quarterly data to a semi-annual frequency by averaging the quarters.

In comparison to the forecasts of government consumption data used in other studies such as Auerbach and Gorodnichenko (2012) and Auerbach and Gorodnichenko (2013), a challenge faced in this study is the data limit of public investment and its deflator. Specifically, forecast data on public investment is not available for some countries, or there are too few observations.[3] As a result, the sample in this study can only cover 14 countries, less than those articles research on the government consumption multipliers.

Macroeconomic data: The major historical quarterly macroeconomic series used in this chapter include real GDP, real government gross fixed capital formation (i.e., public investment), real private consumption expenditure, and real private gross fixed capital formation (i.e., private investment). All series are measured in local currency and with the same base year of 2015. We obtain the data from OECD quarterly national accounts (QNA) database. As the QNA database does not report the historical data for public investment, we collect it from OECD EO that is released in spring, 2019 (i.e., EO No.105).[4] Finally, we convert all the series to the semiannual frequency.

Government debt: Since the data of government debt released by OECD for most of the countries in the sample is only valid from 1995, we obtain the data from the Bank of International Settlements (BIS) Credit to the Non-Financial Sector database. The government debt is measured as total credit to the general government sector at market

[3]The data of public investment is not available for Chile, Colombia, Costa Rica, Czech Republic, Estonia, Hungary, Israel, Lithuania, Latvia, Luxembourg, Poland, Portugal, Slovak Republic, Slovenia, and Turkey. Although OECD forecasts the real public investment for Korea, it does not release the forecasts of nominal public investment or its deflator. Also, we opt out of Austria, Greece, Iceland, Ireland, Italy, Mexico, Spain, and Switzerland from the sample, due to a scarcity of data, especially for years between 2012-2019.

[4]EO No.105 contains forecast data for 2019 and 2020 as well as the historical data for 1985-2018.

value. Dembiermont et al. (2015) demonstrates that BIS series for "public debt" covers loans, debt securities, and currency and deposits that are commonly accounted for the majority of total government debt.[5] Therefore, the concept of public indebtedness is consistent across countries, and thus, the data allows for international comparisons. The data is available with quarterly frequency. To convert data to semi-annual frequencies, we used second quarter observations for the first half of the year and fourth quarter observations for the second half.

Interest rates and CDS: Interest rates can be regarded to reflect the returns on government debt. The quarterly series of short-term (IRST) and long-term (IRLT) interest rates are collected from the OECD Main Economic Indicators database. The interest rates are measured in local currency. We collapse the data to a semi-annual level using the average of corresponding quarterly observations.

Another indicator that measured the cost of borrowing is sovereign CDS. We collect the data of 5 years CDS from Thomson Reuters Datastream. The data is available on a quarterly frequency from 2008Q1 onwards. Again, the quarterly averages are used to convert the data to the semi-annual level.

[5] The measure opts out of other debt instruments mainly because the accuracy of their estimates varies significantly between data sources and countries.

Table 3.2: Availability of key fiscal variables

Country	Public investment forecast error		Real GDP		Government debt		Private consumption		Short-term interest rates		Long-term interest rates		CDS spread	
	first	last	first	last	first	last	first	last	first	last	first	last	first	last
Australia	1997	2018	1985	2018	1988	2018	1985	2018	1985	2018	1985	2018	2009	2018
Belgium	1997	2018	1985	2018	1995	2018	1985	2018	1985	2018	1985	2018	2008	2018
Canada	1986	2018	1985	2018	1990	2018	1985	2018	1985	2018	1985	2018	2008	2018
Denmark	1997	2014	1985	2018	2000	2018	1985	2018	1987	2018	1987	2018	2009	2018
Finland	1996	2018	1985	2018	2000	2018	1985	2018	1987	2018	1988	2018	2008	2018
France	1986	2018	1985	2018	2000	2018	1985	2018	1985	2018	1985	2018	2008	2018
Germany	1991	2018	1991	2018	2000	2018	1991	2018	1991	2018	1991	2018	2008	2018
Japan	1986	2018	1985	2018	1998	2018	1985	2018	2002	2018	1989	2018	2008	2018
Netherlands	1996	2018	1985	2018	2000	2018	1985	2018	1985	2018	1985	2018	2008	2018
New Zealand	1996	2018	1985	2018	1990	2018	1985	2018	1985	2018	1985	2018	2010	2018
Norway	1996	2018	1985	2018	2000	2018	1985	2018	1985	2018	1985	2018	2009	2018
Sweden	1996	2018	1985	2018	1996	2018	1985	2018	1985	2018	1987	2018	2009	2018
United Kingdom	1985	2018	1985	2018	2000	2018	1985	2018	1986	2018	1985	2018	2009	2018
United States	1996	2018	1985	2018	1985	2018	1985	2018	1985	2018	1985	2018	2008	2018

Table 3.3: Descriptive statistics

Country	Long-term interest rates		Short-term interest rates		CDS spread		Debt/GDP ratio		Public investment forecast error		Real GDP (log)		Private consumption (log)	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Australia	7.036	3.496	6.779	4.388	0.437	0.233	93.297	33.711	0.386	0.443	13.9	0.316	13.317	0.341
Belgium	5.237	2.814	3.957	3.240	0.572	0.533	62.296	5.463	0.511	0.291	12.699	0.198	12.067	0.165
Canada	5.589	2.941	4.608	3.444	0.413	0.259	64.031	19.196	0.699	0.487	14.204	0.240	13.578	0.284
Denmark	5.076	3.191	4.320	3.718	0.308	0.301	143.300	30.935	0.979	0.467	14.347	0.166	13.61	0.146
Finland	5.337	3.717	4.351	4.304	0.279	0.153	65.722	18.878	0.954	0.544	12.055	0.221	11.393	0.219
France	5.210	2.991	4.193	3.487	0.389	0.289	80.559	9.658	0.850	0.463	14.406	0.179	13.782	0.179
Germany	3.922	2.324	2.971	2.654	0.200	0.152	87.929	8.933	0.413	0.262	14.789	0.109	14.195	0.077
Japan	2.124	1.881	0.277	0.244	0.347	0.186	105.684	6.484	-0.629	0.982	19.971	0.133	19.386	0.137
Netherlands	4.611	2.388	3.534	2.770	0.381	0.283	95.964	22.95	0.539	0.395	13.214	0.225	12.496	0.182
New Zealand	7.429	3.862	7.699	5.450	0.433	0.221	111.214	34.07	0.027	0.864	12.066	0.283	11.475	0.307
Norway	6.129	3.607	5.921	4.255	0.191	0.075	68.143	12.399	0.715	0.428	14.679	0.235	13.707	0.301
Sweden	5.552	3.747	4.891	4.511	0.239	0.216	105.348	18.217	1.323	0.874	14.959	0.227	14.183	0.211
United Kingdom	5.797	3.092	5.362	4.065	0.409	0.265	82.626	14.071	0.507	0.419	14.199	0.222	13.73	0.26
United States	5.211	2.351	3.790	2.767	0.286	0.135	51.310	4.373	0.623	0.364	16.406	0.258	15.982	0.284

Notes: The table reports mean and standard deviation (SD) for key macroeconomic variables used in this chapter.

3.3.2 Empirical methodology

We follow Auerbach and Gorodnichenko (2012, 2013), and Abdul et al. (2016) to identify public investment shocks as forecast errors of public investment. We believe that by removing the predictable part, the forecast errors could eliminate the problem of “fiscal foresight”. To be specific, the forecast error of public investment as a share of GDP is defined as

$$Shock_{i,t} = AGI_{i,t} - FGI_{i,t}, \tag{3.1}$$

where $AGI_{i,t}$ and $FGI_{i,t}$ are the actual and forecast series of public investment as a share of GDP of country i in time t. In the benchmark case, forecasts for time t are made at time t. That is, the projected data for the first half-year is collected from the OECD Economic Outlook published in Spring in the same year and the forecasts for the second-half year come from the fall version of the Economic Outlook for the same year. We also use the data predicted one period earlier (i.e., forecasts for time t are made at time $t-1$) for the robustness check.

Next step, we use the local projection method of Jordà (2005) to explore the effect of public investment on output and other macroeconomic aggregates. Numerous researchers have used the local projection method because it is easily adaptable to non-linearity, allowing it to be used to estimate a state-dependent model.Auerbach and Gorodnichenko (2012, 2013) point out that this approach is identical to smooth transition vector autoregressive (STVAR) model, but with additional advantages. Compared to estimating of a STVAR model for each state, the critical advantage of the local projection method is that it allows the impulse response function for a particular dependent variable of interest to be calculated separately using a larger number of observations, hence enhancing the accuracy and stability of the estimation. Specifically, we estimate the response of various dependent variables to the public investment shocks at the horizon h from the following regression specification:

$$Y_{i,t+h} - Y_{i,t-1} = \beta^h Shock_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h, \tag{3.2}$$

where $Y_{i,t}$ denotes the variable of interest (i.e., the log of real GDP, the private consumption-to-GDP ratio, the interest rates, and CDS); *Shock* is the unanticipated public investment shock, identified from Equation (3.1); α and γ are the country and time fixed effect, respectively; We estimate Equation (3.2) for each $h = 0,...,5$, where $h = 0$ is the year when the public investment shock occurs. We compute the impulse response functions of variables of interest with the estimated β^h. The confidence intervals associated with the impulse response functions are obtained by the estimated (clustered robust) standard errors of the coefficient β^h.

To examine how the effectiveness of public investment varies with the level of public debt, we allow the public investment shock to interact with the debt-to-GDP ratio in time t and consider the following nonlinear regression:

$$Y_{i,t+h} - Y_{i,t-1} = \beta^h Shock_{i,t} + \delta^h Shock_{i,t} D_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h, \tag{3.3}$$

with
$D_{i,t} = 1$ if $(\frac{Debt}{GDP})_{i,t} \geqslant$ a public debt threshold; and 0 otherwise.

This study defines a strong debt regime as a state where the government debt ratio is less than a specific low threshold, whereas a weak debt regime has a debt ratio exceeding a high critical value. In the next section, we present the results based on the assumption that the countries are in a strong debt regime if their debt-to-GDP ratio is less the 10^{th} percentile in the sample while countries with the debt ratio surpassing 90^{th} percentile will be viewed as in a weak debt regime. Therefore, $\{\beta^h\}_{h=0}^H$ gives the estimated impulse responses for the strong debt regime when the public debt threshold is selected to be the 10^{th} percentile in the sample, and $\{\beta^h + \delta^h\}_{h=0}^H$ measures the impulse responses in a weak debt state if the public debt threshold is the 90^{th} percentile within the sample. We also present the results for alternative debt states (i.e., 20^{th} and 80^{th} percentiles) as a robustness exercise.

To examine the channels through which the government debt can affect the output effect of public investment shock, we expand Equation (3.3) by adding the private consumption and short-term interest rate as control variables and allowing them to interact with government debt. Specifically, we compute the impulse response of output to a public investment shock using the following Equation:

$$\begin{aligned} Y_{i,t+h} - Y_{i,t-1} = \beta^h Shock_{i,t} + \delta^h Shock_{i,t} D_{i,t} + \zeta^h C_{i,t} + \iota^h C_{i,t} D_{i,t} \\ + \mu^h i_{i,t} + \psi^h i_{i,t} D_{i,t} + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h, \end{aligned} \tag{3.4}$$

where $C_{i,t}$ and $i_{i,t}$ denote for the private consumption and short-term interest rate for country i at time t, respectively.

3.4 Empirical findings

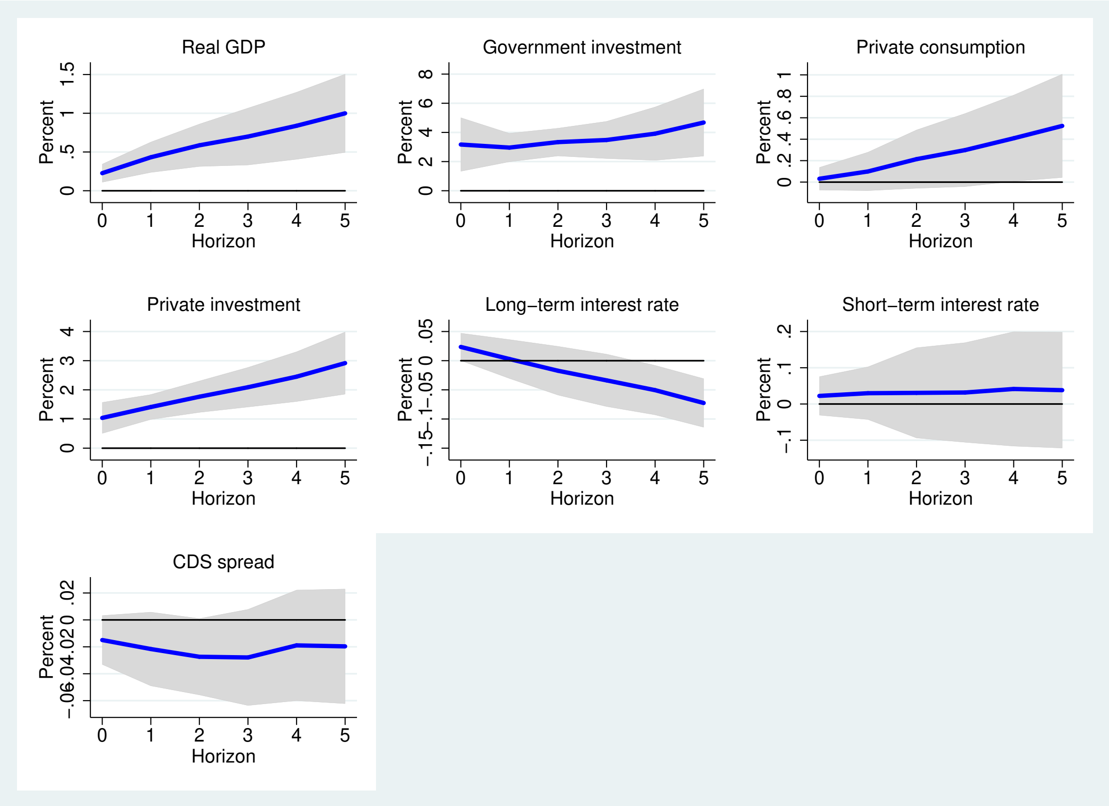
This session summarizes the results for the responses to the public investment shocks based on the estimations of Equation (3.2)-Equation (3.4). The objection is to identify the public investment shocks and explore whether the effectiveness of public investment depends on fiscal sustainability or not.

3.4.1 Baseline results

First, we examine the linear responses of key macroeconomic variables to public investment shocks. Figure 3.3 presents the impulse responses to an unanticipated increase in public investment by one percentage point of GDP. The horizontal axes in this figure and subsequences show the horizons after the shock, and the vertical axes measure the deviation from pre-shock in percent of GDP. The shaded areas indicate 90% confidence bands. Table 3.4 reports the corresponding point estimates and standard errors for the estimated impulse responses for $h = 0, ..., 5$ and the average effect over six semesters. All regressions include a complete set of country and year fixed effects.[6]

Our findings are consistent with other estimates of the public investment multiplier (e.g.Abdul et al. (2016)). That is, the public investment shocks have statistically significant effects on output. The first panel of Figure 3.3 shows that the positive response of Real GDP to a public investment shock is increasing over the reported horizons. An unanticipated increase in public investment of 1 percent of GDP increases the level of output by 0.227 percent in the same semester and about 1 percent three years after the shock. When we use the sample average public investment to GDP ratio ($\approx$3.69) to convert the changes in percentage to level changes, the size of the public investment multiplier is approximately 0.8 for $h = 0$ and 3.7 for $h = 5$. The average response over three years is about 0.63 percentage point increase, which implies the average public investment multiplier is about 2.3 in the short term. The results indicate that the public investment shocks have an increasing and lengthy effect on output.

[6]The country fixed effect captures all time-invariant variances across countries, whereas the time fixed effect can be used to control for business cycles or the global macroeconomic changes.



Notes: The graphs plots the cumulative impulse responses of varies macroeconomic variables to public investment shocks for specification 1 (i.e., Equation (3.2)). $h = 0$ is the period when shock occurs. The shaded bands are 90% confidence bands, which are based on clustered robust standard errors.

Figure 3.3: Impulse responses to public investment (Linear)

Table 3.4: Linear responses to public investment shocks

Variable	h=0 (1)	h=1 (2)	h=2 (3)	h=3 (4)	h=4 (5)	h=5 (6)	Average (7)
Real GDP	0.227***	0.432***	0.587***	0.700***	0.839***	0.999***	0.631***
	(0.071)	(0.120)	(0.167)	(0.224)	(0.264)	(0.308)	(0.093)
Government Investment	3.172***	2.963***	3.337***	3.484***	3.916***	4.680***	3.592***
	(1.120)	(0.596)	(0.581)	(0.778)	(1.115)	(1.404)	(0.519)
Private Consumption	0.031	0.099	0.214	0.299	0.409*	0.524*	0.263***
	(0.064)	(0.109)	(0.166)	(0.208)	(0.245)	(0.293)	(0.088)
Private Investment	1.037***	1.412***	1.765***	2.090***	2.453***	2.917***	1.946***
	(0.324)	(0.262)	(0.329)	(0.414)	(0.520)	(0.649)	(0.235)
Long-term interest rate	0.023	0.002	-0.017	-0.033	-0.050*	-0.072***	-0.024
	(0.014)	(0.020)	(0.025)	(0.027)	(0.025)	(0.025)	(0.016)
Short-term interest rate	0.022	0.029	0.030	0.031	0.041	0.038	0.032
	(0.032)	(0.044)	(0.075)	(0.083)	(0.096)	(0.097)	(0.040)
CDS spread	-0.015	-0.021	-0.027	-0.027	-0.018	-0.019	-0.021**
	(0.011)	(0.016)	(0.017)	(0.021)	(0.025)	(0.025)	(0.011)

Notes: The table reports estimated responses of variables of interest to public investment shocks identified as the forecast error of public investment as a share of GDP. Parentheses denote standard errors. The test statistics are calculated based on the standard errors clustered at the country level. All regressions include a full set of country and year fixed effects.

The impulse response of public investment is strong and persistent in the short term. A positive public investment shock of one percent of GDP can increase public investment by about 3 percent in the same semester, and by 3.6 percent on average over three years.

Additionally, We observe a considerable crowding-in effect of public investment on private investment in the short run, with the maximum response to an unanticipated one percent public investment shock being approximately 3 percent and the average response of private investment to public investment shocks being about 2 percent over three years after the shock. This conclusion could be explained by the expansion of the economy's productive capacity as a result of public investment in physical infrastructure.

While the point estimates for the response to private consumption are positive, the effects are statistically insignificant during the first four sessions but become significant after the second year. The stimulus effect, on the other hand, is relatively minimal.

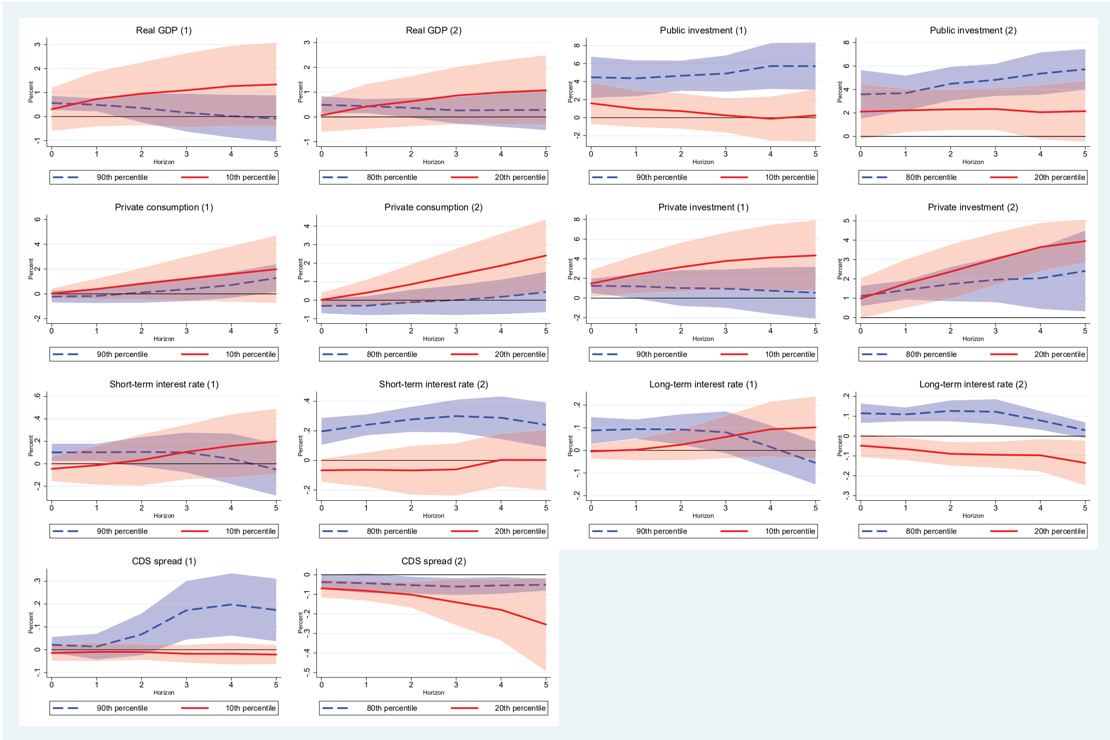
Finally, the interest rates and CDS spread are included to measure the cost of borrowing. We find that public investment shocks have not been associated with significant increases in borrowing costs in our sample. While the responses of short-term interest rate are positive, the null hypothesis of zero response cannot be rejected for all horizons; The responses of long-term interest rate and CDS even turn to be negative and insignificant for most horizons. The results imply that public investment shocks have a negligible effect on borrowing costs.

3.4.2 The role of fiscal sustainability

Figure 3.4 shows impulse responses of key macroeconomic variables to an unanticipated increase in public investment of 1 percentage point of GDP. Each panel in this figure shows impulsing responses in a strong debt regime (red, solid line) and a weak debt regime(blue, dashed line). For each macroeconomic variable, we estimated the responses to public investment shocks that depend on two different sets of fiscal regimes: In subpanels (1), the strong debt regimes are the economies with government debt to GDP ratio in the 10^{th} percentile (i.e., below 29%) and the weak debt regimes are the economies with high debt in the 90^{th} percentile (i.e., above 105%). In subpanels (2), the ratios of government debt to GDP correspond to the 20^{th} (strong) and 80^{th} (weak) percentiles from the sample. The shaded areas indicate 90% confidence intervals, which are based on clustered robust standard errors. Table 3.5 reports the corresponding point estimates and standard errors for the estimated impact and average impulse responses, where the impact response measures the contemporaneous response at $h = 0$ and the average response is estimated over three years.

The responses of output vary significantly between debt regimes. On average, public investment shocks generate a stronger response of output in a strong debt regime than in a weak debt regime. Specifically, the response of output to public investment shocks is larger and more significant when debt is low for all horizons reported, except for the contemporaneous horizon. The responses increase across the horizons within three years. In contrast, if the economies are at a high debt regime, the response of output has decreased and even turns to be negative at the 5^{th} horizon. Even if we relax the cut-offs to 20^{th} and 80^{th}, the results still hold, but the responses are more persistent than in the strict cut-offs (i.e., 10^{th} and 90^{th}). If we use the sample average public investment to GDP ratio ($\approx$3.69) to convert the changes in percentage to level changes, the average public investment multiplier is about 3.5 in a strong debt regime and about 0.9 in a weak debt regime. Our findings corroborate existing theoretical discoveries that the fiscal policy efficiency can be harmed by excessive public debt relative to output (Perotti, 1999; Corsetti et al., 2012).

In the case of public investment, the impulse responses to public investment shocks are stronger and more persistent in the weak debt regime than in the strong debt regime. On the other hand, the average response is greater when the public debt regime is weak than strong, with about a 4 percent difference on average. The result implies that the government invests more when the economy is in a weak fiscal regime.



Notes: The graphs plots the cumulative impulse responses of varies macroeconomic variables to public investment shocks for specification 2 (i.e., Equation (3.3-3.4)). $h = 0$ is the period when shock occurs. The shaded bands are 90% confidence bands, which are based on clustered robust standard errors. The strong debt regime corresponds to the 10^{th} percentile of debt-to-GDP ratio, whereas the weak debt regime corresponds to the 90^{th} percentile of debt-to-GDP ratio in graphs (1); The strong debt regime corresponds to the 20^{th} percentile of debt-to-GDP ratio whereas the weak debt regime corresponds to the 80^{th} percentile of debt-to-GDP ratio in graphs (2).

Figure 3.4: Impulse responses to public investment: The role of public debt sustainability

As discussed before, public debt may go through two channels to affect the effectiveness of public investment: Ricardian equivalence channel (private consumption effect) and sovereign risk channel (costs of borrowing effect). Our empirical results find evidence for both channels. First of all, both subpanels of Figure 3.4 for the impulse responses of private consumption show that the responses are larger in the strong fiscal regime than in the weak fiscal regime. When the debt-to-GDP ratio is high, the public investment shocks tend to decrease the private consumption in the first few periods after the shocks occur, indicating the presence of the Ricardian equivalence channel. Also, Table 3.5 reports statistically significant estimate points of private consumption in a strong debt regime. Conversely, although the responses shown in Figure 3.4 are positive after the contemporaneous horizon, Table 3.5 shows that the estimates on average have no statistical difference from zero in the weak regime. Our finding contributes to the existing literature on the Ricardian equivalence by providing evidence that when debt relative to the output is high, the public investment shocks cannot generate an increase in private consumption, thus reducing the effectiveness of public investment on stimulating the economy.

Public debt may also affect the effectiveness of public investment through the interest rate channel. In our empirical study, short-term and long-term interest rates and CDS spreads are used to measure the cost of borrowing.[7] Figure 3.4 demonstrates that public investment shocks tend to increase the short-and long-term interest rates in a weak debt regime because of the uncertainty, whereas the interest rates drop first after the shocks and then increase in a strong debt regime. Compared to interest rates, CDS spreads is a more direct indicator of borrowing costs. Figure 3.4 shows a strong positive effect of public investment shocks on CDS spreads in the weak debt regime and a negligible effect in the strong debt regime, which can also support the sovereign risk channel. Although the response of CDS spreads turns negative by using alternative cut-offs of debt regimes, the negative effect is larger in a strong debt regime than in a weak debt regime. Moreover, Column (5) of Table 3.5 reports that the average responses of short-and long-interest rates and CDS spreads are all significantly positive, whereas the linear effect (Column (1)) and the response in the strong debt regime (Column (2)) are minimal. Our findings provide evidence on the presence of the sovereign risk channel. The high

[7]Note that the CDS spread data is only valid after 2008 (see Table 3.2), it limits our sample when estimating the responses of CDS spread.

Table 3.5: Responses to public investment shocks: The role of public debt sustainability

Panel A: Average response					
	Linear	Strong debt state		Weak debt state	
Variable		10th percentile	20th percentile	80th percentile	90th percentile
	(1)	(2)	(3)	(4)	(5)
Real GDP	0.631***	0.950**	0.675**	0.353*	0.254
	(0.093)	(0.387)	(0.338)	(0.132)	(0.181)
Government Investment	3.592***	0.616	2.196***	4.029***	4.611***
	(0.519)	(0.712)	(0.738)	(0.383)	(0.496)
Private Consumption	0.263***	1.009**	1.149***	-0.058	0.278
	(0.088)	(0.432)	(0.331)	(0.203)	(0.232)
Private Investment	1.946***	3.214***	2.621***	1.779***	0.955*
	(0.235)	(0.840)	(0.434)	(0.359)	(0.565)
Long-term interest rate	-0.024	0.046	-0.088***	0.097***	0.052***
	(0.016)	(0.029)	(0.029)	(0.016)	(0.023)
Short-term interest rate	0.032	0.073	-0.042	0.257***	0.067*
	(0.040)	(0.075)	(0.056)	(0.034)	(0.048)
CDS spread	-0.021**	-0.015	-0.138***	-0.049***	0.108***
	(0.011)	(0.012)	(0.049)	(0.013)	(0.036)
Panel B: Impact response					
Real GDP	0.227***	0.309	0.064	0.489**	0.569***
	(0.071)	(0.546)	(0.405)	(0.209)	(0.177)
Government Investment	3.172***	1.597	2.109	4.489***	4.371***
	(1.120)	(1.414)	(1.424)	(1.389)	(1.209)
Private Consumption	0.031	0.029	0.019	-0.308	-0.219
	(0.064)	(0.246)	(0.231)	(0.244)	(0.287)
Private Investment	1.037***	1.482*	0.984	1.113***	1.247***
	(0.324)	(0.829)	(0.632)	(0.317)	(0.437)
Long-term interest rate	0.023	-0.004	-0.048	0.115***	0.088**
	(0.014)	(0.020)	(0.034)	(0.029)	(0.035)
Short-term interest rate	0.022	-0.045	-0.067	0.196***	0.101**
	(0.032)	(0.066)	(0.047)	(0.055)	(0.047)
CDS spread	-0.015	-0.014	-0.069**	-0.037*	0.021
	(0.011)	(0.020)	(0.028)	(0.021)	(0.021)

Notes: The table reports estimated responses of variables of interest to public investment shocks identified as the forecast error of public investment as a share of GDP. Parentheses denote standard errors. The test statistics are calculated based on the standard errors clustered at the country level. All regressions include a full set of country and year fixed effects. The strong debt regime corresponds to the 10^{th} percentile of debt-to-GDP ratio in column (2), and 20^{th} percentile of debt-to-GDP in column (3); whereas the weak debt regime corresponds to the 80^{th} percentile of debt-to-GDP ratio in column (4) and 90^{th} percentile of debt-to-GDP ratio in column (5). The average response is calculated over three years. The impact response is calculated for $h = 0$.

level of public debt increases uncertainty for investors, and thus, risk-averse investors demand a higher risk premium. As a result, a weak debt regime may experience greater borrowing costs than a strong debt regime.

3.5 Robustness checks

This section presents the responses of output for various robustness checks. Table 3.6 shows the responses of output for alternative measures of public investment shocks.

First of all, instead of using the forecasts of the public investment made in the same period, We use the forecasts of public investment for time t which made at time $t-1$ to compute the public investment forecast errors, which is denoted as $FE_{i,t|t-1}$. The estimated results are shown in Column (2) of Table 3.6. Comparing it with our baseline results (Column (1)), we find no statistically significant difference between these two results.

Secondly, some may argue that the forecast error for public investment cannot be identified as exogenous public investment shock because it may be correlated with other macroeconomic variables. To avoid the concern, we purify the forecast errors by regressing the public investment forecast errors on the lags of other macroeconomic variables, including real GDP, public investment, and changes in the market exchange rates.[8] The purified forecast errors are estimated using the residuals from the regression. The results in Column (3) of Table 3.6 show that the point estimates using the purified shock are basically identical with the baseline estimates.

Thirdly, the exogenous public investment shock is identified as the forecast error of public investment as a share of GDP in the baseline estimation. Thus it may be endogenously correlated with the output growth innovations. Although the changes in economic conditions mainly affect the tax revenues and transfer payments, they may also affect public investment. To eliminate the potential effect of output growth innovations on the forecast error of public investment, we regress the forecast error of public investment on the forecast error of GDP growth and identify the purified public investment shock as the estimated residuals. Column (4) of Table 3.6 presents the responses of output to this purified public investment shocks. The points estimates are almost

[8]The lag lengths we used in the regression is 4.

identical with the baseline results, which indicates our baseline findings are robust.

We also follow Auerbach and Gorodnichenko (2013) to estimate the public investment shocks as the forecast errors of public investment growth rate. The results are shown in Column (5) of Table 3.6. The average output responses over six horizons are almost identical to the baseline results, although there are no statistically significant in the contemporaneous horizon and the last reported horizon.

Table 3.7 reports the responses of output depending on different fiscal regimes using alternative identification methods of public investment shocks.[9] All the robustness checks indicate that on average over three years, the responses of output to public investment shocks are larger in a strong debt regime than in a weak debt regime, although the estimates points vary across different measures and different horizons. The results imply that our findings are robust with alternative identification methods of public investment shocks.

[9] In table 3.7, we only report the results when the debt ratio is in the 10^{th} percentile (i.e., Strong) in the first column of each panel and 90^{th} percentile (i.e., Weak) in the second column of each panel. The results for the alternative cut-offs (20^{th} and 80^{th}) are almost identical.

Table 3.6: Alternative measures of public investment shocks

Horizons	Baseline	$FE_{i,t\|t-1}$	Purified Shock from Macro variables	Purified Shock from Growth	Growth rate
	(1)	(2)	(3)	(4)	(5)
h=0	0.227***	0.214***	0.255**	0.223***	0.199
	(0.071)	(0.0696)	(0.101)	(0.0717)	(0.124)
h=1	0.432***	0.367***	0.433***	0.427***	0.442**
	(0.120)	(0.101)	(0.132)	(0.120)	(0.216)
h=2	0.587***	0.471***	0.543***	0.580***	0.569**
	(0.167)	(0.130)	(0.167)	(0.168)	(0.247)
h=3	0.700***	0.581***	0.618***	0.693***	0.703***
	(0.224)	(0.167)	(0.216)	(0.225)	(0.237)
h=4	0.839***	0.715***	0.706***	0.832***	0.595*
	(0.264)	(0.207)	(0.253)	(0.265)	(0.308)
h=5	0.999***	0.854***	0.827***	0.993***	0.509
	(0.308)	(0.245)	(0.298)	(0.309)	(0.336)
Average	0.631***	0.534***	0.563***	0.625***	0.503***
	(0.093)	(0.070)	(0.089)	(0.094)	(0.105)

Notes: The table reports estimated responses of variables of interest to alternative measures of public investment shocks. Parentheses denote standard errors. The test statistics are calculated based on the standard errors clustered at the country level. All regressions include a full set of country and year fixed effects.

Table 3.7: Alternative measures of public investment shocks: The role of public debt sustainability

					Purified Shock from					
	Baseline		$FE_{i,t\|t-1}$		Macro variables		Growth		Growth rate	
Horizons	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak	Strong	Weak
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
h=0	0.309	0.569***	0.383	0.596***	0.279	0.573***	0.697	0.622***	0.794*	0.042
	(0.546)	(0.177)	(0.489)	(0.168)	(0.431)	(0.183)	(0.569)	(0.199)	(0.467)	(0.461)
h=1	0.734	0.490***	0.631	0.571***	1.128*	0.465***	1.315**	0.530***	0.853	0.169
	(0.695)	(0.165)	(0.666)	(0.151)	(0.645)	(0.163)	(0.643)	(0.168)	(1.321)	(0.394)
h=2	0.953	0.360	0.831	0.482	1.538**	0.339	1.652**	0.411	0.517	0.884
	(0.797)	(0.364)	(0.848)	(0.326)	(0.712)	(0.341)	(0.690)	(0.351)	(1.446)	(0.770)
h=3	1.098	0.164	1.022	0.318	1.945**	0.158	1.859**	0.226	1.559	0.903
	(0.938)	(0.479)	(1.026)	(0.408)	(0.898)	(0.443)	(0.798)	(0.462)	(1.937)	(1.111)
h=4	1.272	0.020	1.103	0.195	2.401**	-0.004	2.089**	0.066	1.482	0.078
	(1.022)	(0.541)	(1.135)	(0.464)	(1.028)	(0.501)	(0.871)	(0.534)	(1.775)	(0.871)
h=5	1.338	-0.078	1.232	0.179	2.506**	-0.124	2.127**	-0.050	2.067	0.025
	(1.062)	(0.589)	(1.210)	(0.489)	(1.082)	(0.573)	(0.934)	(0.604)	(1.661)	(0.703)
Average	0.950**	0.254	0.867**	0.390**	1.633***	0.234	1.623***	0.301*	1.212**	0.350
	(0.387)	(0.181)	(0.401)	(0.151)	(0.358)	(0.179)	(0.349)	(0.181)	(0.590)	(0.321)

Notes: The table reports estimated responses of variables of interest to alternative measures of public investment shocks. Parentheses denote standard errors. The test statistics are calculated based on the standard errors clustered at the country level. All regressions include a full set of country and year fixed effects. The strong debt regime corresponds to the 10^{th} percentile of debt-to-GDP ratio whereas the weak debt regime corresponds to the 90^{th}.

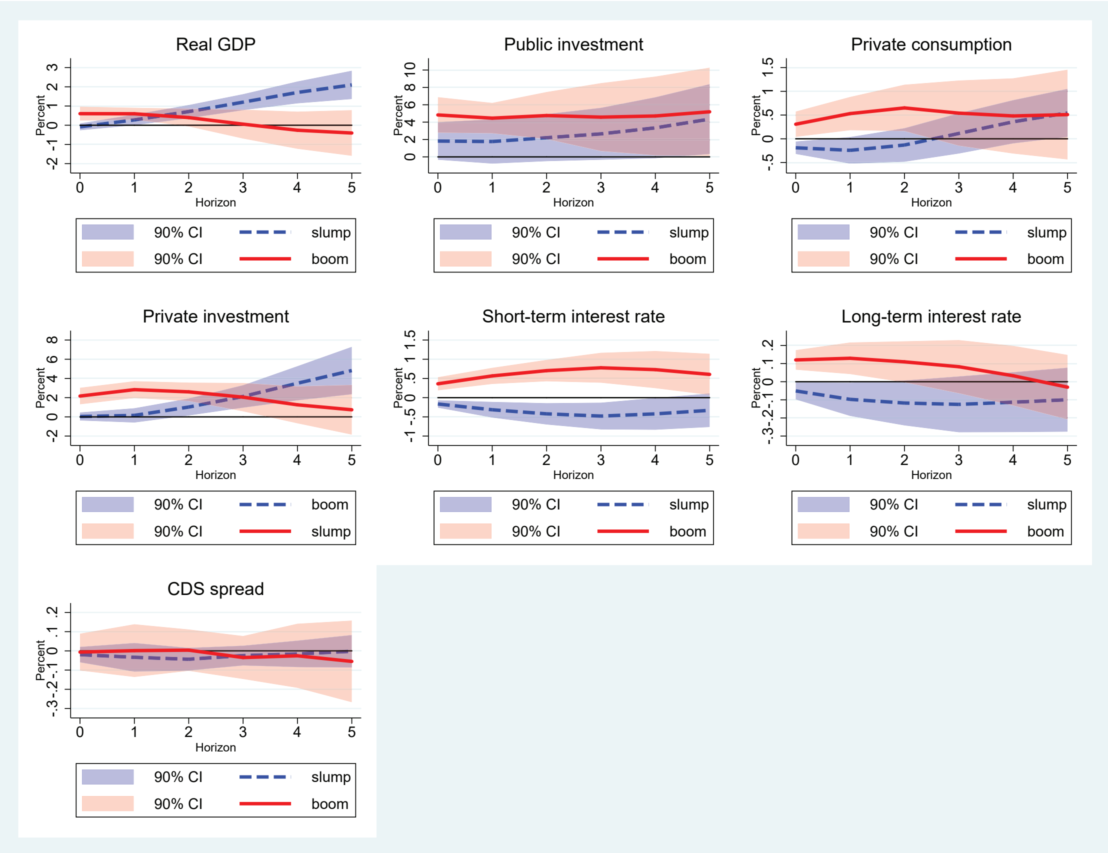
3.5.1 The role of economic conditions

A large body of literature has reported that the effect of fiscal shocks can vary according to the economic conditions e.g., Auerbach and Gorodnichenko, 2012, 2013, 2017; Jordà and Taylor, 2016; Abdul et al., 2016; Huidrom et al., 2020. The economies may accumulate a tremendous amount of public debt in the recession than in the expansion. As a result, the effect of public investment shocks we have discussed may depend only on the economic conditions rather than the public debt sustainability. To examine if our findings are robust when considering the economic conditions, we estimate responses of key macroeconomic variables to public investment shocks with interaction with the economic conditions and public debt regimes. Before that, we first examine if the responses vary with the business cycle. Specifically, we do the following specification:

$$Y_{i,t+h} - Y_{i,t-1} = \beta^h Shock_{i,t} + \lambda^h Shock_{i,t} S(z_{i,t}) + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h, \tag{3.5}$$

where $z_{i,t}$ measures the state of economy and following Auerbach and Gorodnichenko (2012) and Auerbach and Gorodnichenko (2013), $S(z_{i,t}) = \frac{\exp(-\theta z_{i,t})}{1+\exp(-\theta z_{i,t})}$ with $\theta = 1.5$. The function is employed to estimate the likelihood of an country being in the weak economic regime (i.e., recession). Thus, $S(z_{i,t}) = 1$ indicates that the economy is in a recession, whereas $S(z_{i,t}) = 0$ represents an economy that is experiencing an expansion. $z_{i,t}$ measures the deviation of output from its trend. We follow Auerbach and Gorodnichenko (2012) and Auerbach and Gorodnichenko (2013) to use the Hodrick-Prescott filter with a high smoothing parameter (i.e., $\lambda = 10,000$) to extract the unobserved trend from actual output. By doing so, $z_{i,t}$ has a mean of zero. We then divided it by its standard deviation such that the deviation of output from its trend has unit variance and the results are more comparable across countries. In other words, $z_{i,t}$ can be measured using the following equation:$z_{i,t} = \log(\frac{GDP_{i,t}}{GDP_{i,t}^{trend}})/\text{std}(\log(\frac{GDP_{i,t}}{GDP_{i,t}^{trend}})$.

The impulse responses of key macroeconomic variables to public investment shocks are presented in Figure 3.5 for slump (blue, dashed line) and boom (red, solid line). The first panel shows the response of output to a public investment shock. When the economy is in expansion, the response is positive in the contemporary period when the shock occurs, but it decreases across the reported horizons and turns negative after the second year. In contrast, a public investment shock is associated with an increasing and persistent response of output in recession. Additionally, after the first horizon, the output response is significantly larger in a weak economic regime than in a strong economic regime. Our finds are consistent with earlier studies (e.g., Auerbach and Gorodnichenko, 2012, 2013, 2017; Jordà and Taylor, 2016; Abdul et al., 2016; Huidrom et al., 2020).



Notes: The graphs plots the cumulative impulse responses of varies macroeconomic variables to public investment shocks for specification 3 (i.e., equation (3.5)). $h = 0$ is the period when shock occurs. The shaded bands are 90% confidence bands, which are based on clustered robust standard errors.

Figure 3.5: Impulse responses to public investment: the role of economic conditions

We also find a larger response of public investment when the economy is in a boom than in a slump state. In the case of private consumption, The response to a public investment shock is positive in expansions across all reported horizons. However, due to the high uncertainty in recession, an expansionary fiscal policy cannot enhance private consumption during the first three horizons but begins to do so after that. Additionally, Figure 3.5 shows the effect of public investment shocks on private investment. An economy in a boom state experiences a positively increasing response of private investment, whereas the expansionary effect in recessions tends to diminish over the given horizons.

Moreover, We find a similar result as in Auerbach and Gorodnichenko (2017) that expansionary fiscal policies adopted when the economy is weak can stimulate output and at the same time reduce interest rates and CDS spreads on government debt, while the outcomes when the economy is strong are more likely to have the conventional effects. As indicated Auerbach and Gorodnichenko (2017), this finds implies that an expansionary fiscal policy is viewed as a positive signal in terms of recovering the economy and mitigating risks in a deep recession, hence increasing the market confidence and lowering the borrowing costs.

To demonstrate that public debt sustainability does have an impact on the effectiveness of public investment and that the effect is not due to business cycles, we estimate responses of key macroeconomic variables to public investment shocks with interaction with the economic conditions and public debt regimes and examine whether the effect varies within the same economic condition. In particular, we rewrite specification 3.2 by adding the state of the economy:

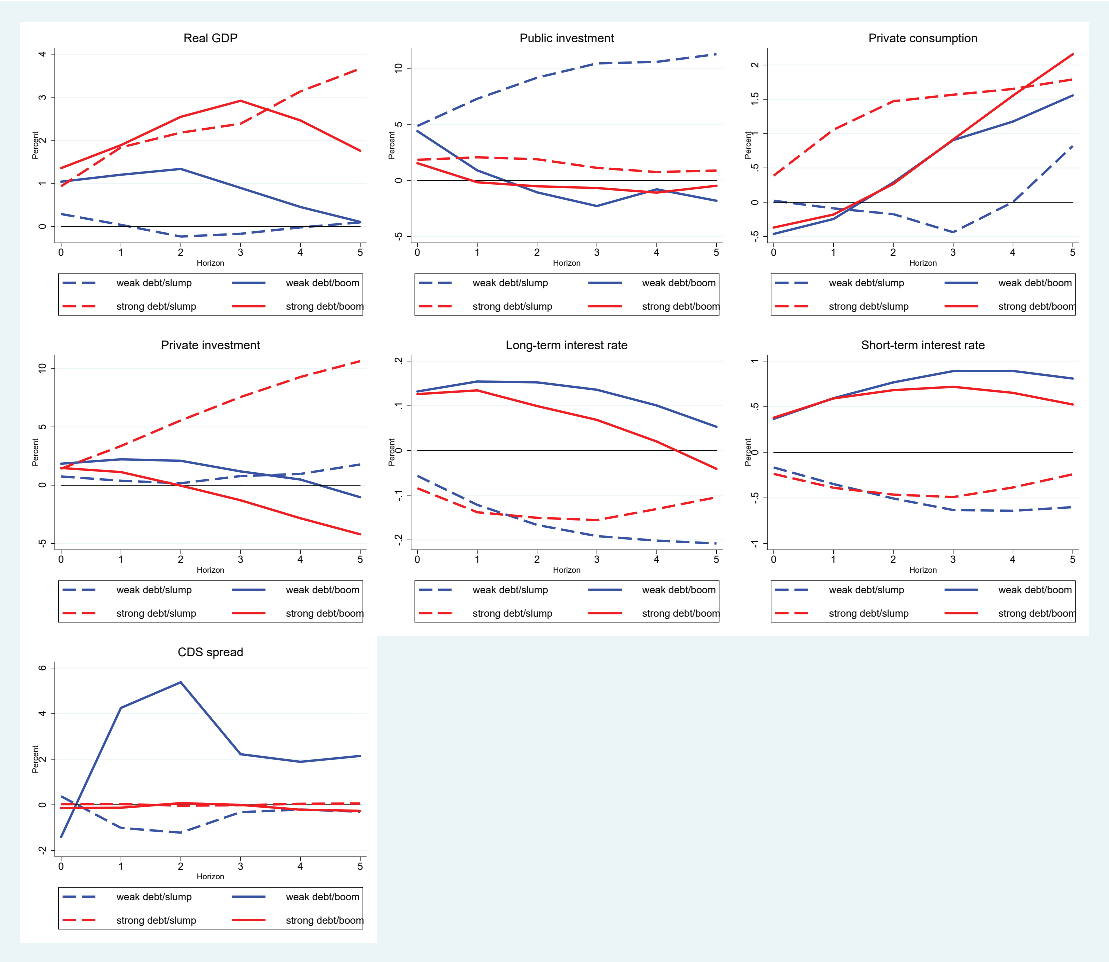
$$\begin{aligned} Y_{i,t+h} - Y_{i,t-1} = \beta^h Shock_{i,t} + \delta^h Shock_{i,t} D_{i,t} + \kappa^h Shock_{i,t} S(z_{i,t}) \\ + \eta^h Shock_{i,t} D_{i,t} S(z_{i,t}) + \alpha_i^h + \gamma_t^h + \varepsilon_{i,t}^h \end{aligned} \tag{3.6}$$

Combining these two interactions, $\{\beta^h\}_{h=0}^H$ and $\{\beta^h + \delta^h\}_{h=0}^H$ measure the casual effects of public investment shocks on a variable of interest at horizon $h = 0,...,5$ in strong-debt/boom state and weak-debt/boom state, respectively; whereas $\{\beta^h + \kappa^h\}_{h=0}^H$ and $\{\beta^h + \delta^h + \kappa^h + \eta^h\}_{h=0}^H$ provide the response in a strong-debt/slump state and a weak-debt/boom state, respectively.

Figure 3.6 depicts the impulse responses of key macroeconomic variables to the public investment shocks when we consider interactions between the public debt regimes and the economic conditions.[10] The following analyses are based on the results corresponding to the 10^{th} percentile and 90^{th} percentile of debt-to-GDP ratios in our sample. In each panel of Figure 3.6, the solid, blue line and the solid, red line represent the responses in a weak-debt/boom state and a strong-debt/boom state, respectively; the dashed, blue line and the dashed, red line represent the responses in a weak-debt/slump

[10]To save the space, we only plot the impulse responses but not the confidence intervals.

state and a strong-debt/slump state, respectively.



Notes: The graphs plots the cumulative impulse responses of varies macroeconomic variables to public investment shocks for specification 4 (i.e., equation (3.6)). $h = 0$ is the period when shock occurs. The shaded bands are 90% confidence bands, which are based on clustered robust standard errors. The strong debt regime corresponds to the 10^{th} percentile of debt-to-GDP ratio, whereas the weak debt regime corresponds to the 90^{th} percentile of debt-to-GDP ratio.

Figure 3.6: Impulse responses to public investment: interaction with the debt regimes and economic conditions

The first panel of Figure 3.6 plots the impulse responses of real GDP to the public investment shocks for four combinations of states. Our results are robust even economic conditions are taken into account. That is, within the same economic conditions (either slump or boom), the responses are significantly larger in a strong-debt regime than in a weak-debt regime. In an economy with a low level of debt relative to GDP, the fiscal multiplier effect is stronger in a recession. However, fiscal expansion cannot be demonstrated as an efficient instrument to stimulate the economy in a slump if the debt-to-GDP ratio is large.

When the economy is in a recession, public investment shocks are associated with positive and stronger responses of public investment in a weak debt regime than in a strong debt regime. In contrast, with in the boom state, the responses drop in general and turn negative after the first horizon for both weak and strong debt regime. Moreover, the impact of public debt sustainability on fiscal stimulus is small in expansions.

The presence of the Ricardian equivalence channel can be well established in a slump state. The economy with a strong debt regime can make effective use of expansionary fiscal policy to stimulate private consumption during economic downturns, since we can observe from Figure 3.6 that the response of private consumption to public investment shock is strong and persistent in a strong debt regime. Conversely, positive public investment shocks in a weak regime can raise the household's concern about higher future taxes, resulting in an increase in precautionary private saving and a drop in private consumption. On the other hand, the responses of private consumption in a boom state cannot provide evidence on Ricardian equivalence, and there is no evidence for the state-dependent behavior of the response over the debt regimes when the economy is in expansion.

Our results show that when the economy is booming, private investment responds similarly to different debt regimes: the positive impact on private investment is relatively limited at the beginning after a public investment shock and even turns negative subsequently. This crowding-out effect can occur when public-funded development on infrastructure (e.g., bridges or roadways) discourages firms from investing in such projects. On the other hand, the non-linear behavior of the responses of private investment is more apparent over debt regimes in recessions. Consistent with our baseline results, the effect of public investment shocks is more significant in a strong debt regime than in a weak debt regime, indicating that increased public investment may drive out some private investment if the debt-to-GDP ratio is too high.

As illustrated in Figure 3.6, the impulse responses of short-and long-term interest rates shown in tend to vary according to the business cycle rather than the debt regimes. Following a public investment shock, increased interest rates are observed in a boom state, whereas the interest rates fall in a slump. The result is consistent with the findings from Figure 3.5. Despite this, the responses perform similarly over the debt regimes within the same economic condition. Finally, Figure 3.6 shows that there is no material effect of public investment shocks on the CDS spread in a strong debt regime, regardless which phases of business cycles the economy in. The finding of a distinctive difference between the response over the business cycle can be found in Figure 3.6, with a rise in recessions and a fall in expansions.

3.6 Conclusion

The impact of public investment on mitigating recessions has been highlighted and explored in earlier theoretical literature (e.g., Krugman, 2016; Aschauer, 1989; Baxter and King, 1993). As a component of aggregate demand, scaling up public investment would boost the economy and create jobs in the short term. More importantly, increased public investment can raise productivity significantly by increasing the public capital stock in the long term. However, a growing body of studies demonstrates how public debt sustainability hamper the effectiveness of public investment. Public debt sustainability can influence the effectiveness of public investment through two channels: The Ricardian equivalence channel and the sovereign risk channel.

This chapter estimates the size of public investment multipliers for 14 OECD countries from 1985 to 2018. The results show that the maximum public investment multiplier for the reported horizons is 3.7, and the average public investment multiplier over three years is about 2.3. We also explore how the effect of public investment stimuli varies according to the public debt regime. Our findings indicate that public debt sustainability indeed affects the effectiveness of public investment. In particular, the response of output to an unanticipated public investment shock is weaker when the economy is in the weak-debt regime than in the strong-debt regime, which implies that a high level of public debt can harm the public investment efficiency. This chapter also provides empirical support on the Ricardian equivalence channel and sovereign risk channel. Specifically, we find that, on the one hand, when debt relative to the output is high, the public investment shocks cannot generate an increase in private consumption, thus reducing the effectiveness of public investment on stimulating the aggregate demand. On the other hand, the short- and long-term interest rates increase at earlier periods after a public investment shock when the debt-to-GDP ratio is high. Although the interest rates fall eventually, on average, the responses are significantly positive and larger in a weak debt regime than in a strong debt regime. A similar result can be obtained by estimating the response of CDS spreads. In a weak debt regime with the debt-to-output ratio is above 90^{th} percentile, a public investment shock lifts the CDS spreads in the short term, whereas the response in an economy with the debt ratio below 10^{th} percentile is negligible.

Our empirical findings indicate that public investment cannot be abused indiscriminately to stimulate the economy while ignoring public debt sustainability. Policymakers should thoroughly examine the public debt situation before implementing an expansionary fiscal package, as their effectiveness in stimulating economic activity is constrained by the sustainability of public debt.

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Chapter 4

Conclusion

This thesis consisted of two essays about fiscal policy and public debt. This chapter summarizes the main findings, identifies gaps in the literature, and discusses potential areas of further study.

Chapter 2 used a Neoclassical growth model to explore the fiscal reform in the UK against the projected increasing government expenditure in order to mitigate the pressure on public debt and reduce the debt ratio to a sustainable value. OBR's projections show that UK's government spending will increase over the next 50 years mainly due to the rise in age-related expenditure, whereas the receipts remain flat, leading to the projected primary budget balance shift from a surplus to a deficit (see Figure 1.2). The projected increase in the primary deficit, in turn, puts upward pressure on public debt, and as a result, the net public debt as a share of output is projected to rise to 234% in 2066-67. Such a high debt ratio has violated the sustainable investment rule (i.e., net public sector debt should not exceed 40% of GDP) and even surpassed the Maastricht criteria (i.e., 60% of GDP for public debt). In fact, the pressures on public sector finances are common to most developed countries. Many developed countries such as Germany and the Netherlands are suffering from a severe population aging problem. In the EU, the old-age dependency ratio is projected to climb dramatically from 34% in 2019 to 59% in 2070, indicating that each people aged 65 and over will be afforded by less than two working-age persons by 2070 (see, European Commission report (2021)).[1]

[1]The old-age dependency ratio is defined as the number of individuals aged 65 and above relative to the working-age population (i.e., the number of people aged between 20 and 64).

Obviously, the age-related expenditures, including pension, education, health, and long-term social care expenditure, will increase in the future and represent a critical challenge on the public fiscal finance. Population aging has been one of the main driving forces for governments to take action to find a way to finance the projected increase in government spending and, at the same time, reduce the public debt to a "stable and prudent" level. Japan, as the oldest super-aged country in the world, its fiscal impact of population aging and corresponding fiscal reform have been widely studied (Braun and Joines, 2015; Kitao, 2015; Imrohoroglu and Sudo, 2011; Hansen and Imrohoroglu, 2016). The existing literature also evolves the study on fiscal reforms regarding the population aging in some other countries, including Australia, the United State, and Germany (Kudrna et al., 2015; Nishiyama, 2015; Botman and Danninger, 2007). In the future study, we will focus on the fiscal impact of aging and the feasible fiscal reform for other relevant countries.

The main finding in Chapter 2 is that the tax revenue to finance the future government expenditures and cut the public debt ratio down to the Maastricht criteria in the steady state is in the range of 20-24% of consumption expenditures. When a distorting tax such as consumption tax or labor income tax is used to achieve the goal, the tax rate must be set to a high level. Specifically, the consumption tax rate needs to increase to above 50%, whereas the labor income tax rate has to rise to over 70%. Even if the government is allowed to consider the tax base broadening, the distorting tax rates are still required to increase to the level of 45%-60%. Also, although both consumption and labor income tax rates distort labor supply, the consumption tax is less distorting than the labor income tax.

Such high levels of the tax rates indicate that using the consumption tax rate or labor income tax rate is not a feasible fiscal policy for the UK government to raise the revenue and mitigate the fiscal burden in the future. This result brings us to find other ways to reduce the fiscal pressures in the future.

One of the possible feasible fiscal reforms is to broaden the tax base. In the further study, we will analyze the effects of different combinations of the following tax bases: (i) lump-sum tax base; (ii) consumption tax base; (iii) labor income tax base; and (iv) capital income tax base.

The capital income tax was not considered in Chapter 2, mainly hinged on the zero capital tax in the optimal taxation theory. It advocates that capital income tax should be avoided. Diamond and Mirrlees (1971) provides an explanation for the zero capital tax: capital should be treated as an intermediate input, therefore, should not be taxed. Another reason is that the capital income tax violates the principle of uniform commodity taxation proposed by Atkinson and Stiglitz (1976) since it levies on future consumption but not on current consumption (Mankiw et al., 2009). Finally, in the Ramsey model, some households are modeled as having an infinite planning horizon. These households decide how much to save based on their future discounting and the economic return on capital. In the long-run equilibrium, their saving decisions are perfectly elastic for the after-tax rate of return. Thus, any tax on capital income will leave the after-tax return to capital unchanged, which means the pre-tax return to capital must rise, reducing the size of the capital stock and aggregate output in the economy. Chamley (1986) and Judd (1985) find that, in the short run, a positive capital tax may be desirable because it is a tax on old capital and, therefore, is not distortionary. In the long run, however, a zero tax on capital is optimal. This distortion is so large as to make any capital income taxation suboptimal compared with labor income taxation, even from the perspective of an individual with no savings (Mankiw, 2000). However, one can find reasons to question the optimally of zero capital taxes. If all individuals have relatively short planning horizons, as in overlapping generations models, capital taxation can provide redistribution without the dramatic effects on capital accumulation identified in the Ramsey literature. Conesa et al. (2009) explore this argument for capital taxation. Alternatively, if individuals accumulate buffer stocks of savings to self-insure against shocks, there may be aggregate overaccumulation of capital, justifying capital taxation, as in Aiyagari (1994).

Given that tax rates have to rise dramatically to cover the anticipated age-related spending in many countries, fiscal adjustment can be appropriately oriented towards the expenditure side (Clements et al., 2010). Because public pension spending comprises a significant share of total spending, efforts to contain these increases will be a necessary part of fiscal consolidation, particularly in advanced economies (Clements et al., 2016). The measures to contain pension spending may include raising the retirement age gradually, reducing the benefit, or increasing the contribution rate.

Other non-fiscal adjustments to mitigate the fiscal burden may include increasing the economic growth rate by improving technology and innovation and increasing the number of working-age people relative to the number of the old-age population, such as reforming the immigration policies and family policies. The target could also be attained through various combinations of expenditure and revenue measures. The feasible policies to mitigate the financial burden are left for future research.

Chapter 3 examines the effects of public debt sustainability on the effectiveness of public investment for a sample of 14 OECD countries from 1986 to 2018. First, following Auerbach and Gorodnichenko (2012), We identify the exogenous public investment shock as the forecast error of public investment relative to output, and we demonstrate that this strategy is capable of resolving the issue of "fiscal foresight". Then we estimate the responses of macroeconomic variables to public investment shocks using the local projection method of Jordà (2005). This method is straightforward and well-established for estimating the nonlinear effects of shocks (see Auerbach and Gorodnichenko, 2012, 2013, 2017; Jordà and Taylor, 2016; Abdul et al., 2016), and thus employed to investigate whether and how the sustainability of public debt affects the effectiveness of public investment.

The results show that the maximum public investment multiplier for the reported horizons is approximately 3.7, and the average public investment multiplier over three years is about 2.3. Additionally, We explore how the effect of public investment stimuli varies according to the public debt regime. Our findings indicate that public debt sustainability indeed affects the effectiveness of public investment. In particular, the response of output to an unanticipated public investment shock is weaker when the economy is in the weak-debt regime than in the strong-debt regime, which implies that a high level of public debt can harm the public investment efficiency. This chapter provides empirical support for the Ricardian equivalence channel and sovereign risk channel. Specifically, we find that when debt relative to the output is high, the public investment shocks cannot generate an increase in private consumption, thus reducing the effectiveness of public investment on stimulating the economy. Moreover, our baseline findings can support the presence of the sovereign risk channel by that the short-and long-term interest rates and CDS spreads increase after a public investment shock in a weak debt regime, whereas the responses are negative at earlier horizons in a high debt regime. On average, the responses of borrowing costs are significantly positive and larger in a weak debt regime than in a strong debt regime. This chapter also estimates the nonlinear effects of public investment by considering the interaction of business cycles and public debt sustainability. The results are similar to baseline results, indicating that our findings are robust.

Our empirical findings emphasize the importance of public investment in economic growth, particularly during times of recession. With a higher multiplier for public investment in a slump than in a boom, public investment should play a critical role in fostering job creation, stimulating demand, and reviving the economy in the short run. However, the effectiveness of public investment is constrained by the sustainability of public debt. That is, a high debt-to-output ratio can reduce the multiplier effect of public investment. On the one hand, excessive debt raises private agents' concerns about the government's ability to repay. Thus, following a public investment shock, private agents reduce consumption today and increase precautionary savings in anticipation of a future tax increase to pay off the increased government debt (Ricardo, 1912). As a result, public investment's ability to stimulate demand is undermined. On the other hand, large public debts increase uncertainty and push up the whole economy's borrowing costs, undermining the effectiveness of fiscal policies. Our findings indicate that public investment cannot be used uncontrolled to stimulate the economy while ignoring public debt sustainability. Fiscal policymakers should adjust fiscal policy to protect people, boost jobs, and recover the economy while also ensuring the sustainability of public debt.

Future studies should concentrate on three points. To begin, while some literature has examined the impact of different compositions of government spending on economic growth both theoretically and empirically (e.g., Baxter and King, 1993; Ambler and Paquet, 1996; Perotti, 2004; Ambler and Paquet, 1996; Ghosh and Gregoriou, 2008), there has been no study exploring if the public debt sustainability has a different impact on different composition of government spending. In the future study, we will examine the relationship between the sustainability of public debt and the effectiveness of government spending composition in a general equilibrium framework. This study will shed light on implementing an effective fiscal policy in the face of rapid debt accumulation. Second, our research is constrained by data availability; as a result, we were able to examine only 14 OECD countries, the majority of which are developed. As a result, our findings may not accurately reflect the relationship between fiscal policy and public debt sustainability in developing countries. Further research might be conducted to determine whether the influence of public debt sustainability on the effectiveness of public investment varies between developed and developing countries.

Finally, one might investigate whether the effectiveness of monetary policy depends on the sustainability of public debt. The forecast error approach can also be applied to identify monetary policy shocks. For example, Furceri et al. (2018) estimates the forecast error of the policy rates as the difference between the actual and forecast policy rates in the short term. Then, they regress the forecast error of the policy rates on the forecast error of inflation and GDP growth. The monetary policy shocks are estimated using the residuals from the regression. Following this approach, the future study could examine the relationship between the effectiveness of monetary policy and public debt sustainability.

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