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The Macroeconomic Effects of Fiscal Consolidation in Dynamic General Equilibrium*

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Abstract

We provide a systematic analysis of the transmission mechanisms of fiscal consolidation via various fiscal instruments in a medium-scale dynamic general equilibrium model. Our analysis shows that the following three aspects have a large impact on the quantitative macroeconomic effects of fiscal consolidation. First, the effects on output depend crucially on the interaction of the specific fiscal consolidation instrument with the production factors labor, private and public capital. Increases in the labor and capital tax rates and cuts in government investment lead to large declines in one of these production factors, respectively. This is followed by a decrease in the private or public capital stock which in turn yields a persistent output contraction. By contrast, for consolidations via government consumption, transfers or the consumption tax rate the capital stock does not shrink and output recovers much faster. Second, the presence of credit-constrained households amplifies the consumption and output dynamics caused by fiscal consolidation. This has large distributional consequences and opposing welfare implications for credit-constrained and fully optimizing households. Finally, when the zero lower bound on the nominal interest rate binds the short-run output costs of fiscal consolidation increase substantially in particular for expenditure based consolidations.

Keywords: fiscal consolidation, policy transmission, government debt, distortionary taxes, zero lower bound, welfare, monetary-fiscal policy interaction
JEL-Codes: E32, E62, E63, H61, H62, H63

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1 Introduction

In the aftermath of the global financial crisis and the Great Recession, many countries are facing substantial deficits and growing debt. As analysed in the 16th Geneva Report on the World Economy (Buttiglione et al., 2014), global debt-to-GDP continues to grow, while growth and inflation remain low, raising concerns about the danger of new crises. This spurs the need to consolidate public finances in order to bring down debt-to-GDP ratios. When setting up specific fiscal consolidation plans, policymakers can generally choose from a wide range of possible fiscal instruments. However, to do so in a meaningful way, they need to understand the specific effects of fiscal consolidation via the different instruments. In this paper, we seek to broaden this understanding by providing a comprehensive analysis of the transmission as well as the overall quantitative effects of fiscal consolidation via six different fiscal instruments on key macroeconomic variables and on welfare.

The literature analyzing the consequences of fiscal consolidation in macroeconomic models is still in its early stage. However, a large related literature studying the effectiveness of fiscal stimulus has developed in recent years. While there is no agreement yet on the size of empirical fiscal multiplier estimates (see e.g. the debate between Ramey, 2011, and Perotti, 2014), the key factors determining the effectiveness of fiscal stimulus, such as the mix of spending instruments, the share of credit-constrained households, the length of a binding zero lower bound (ZLB) on interest rates and the usage of lump-sum or distortionary taxes to return the debt-to-GDP to its initial level are well understood in theoretical models (see e.g. Cogan et al., 2010, Drautzburg and Uhlig, 2011, and Christiano et al., 2011).

Nonetheless, it would be misleading to assume that the effects of fiscal consolidation are just the mirror image of fiscal stimulus. First of all, fiscal stimulus is a temporary policy change that leads to a return to the initial steady state in the long run. On the contrary, the purpose of fiscal consolidation is to bring down government debt permanently, i.e. to arrive at a new steady state with a lower debt-to-GDP ratio. Such permanent changes in fiscal policy can induce much larger effects than temporary changes as shown by Baxter and King (1993) in a neoclassical model. Secondly, the ZLB on interest rates influences the effects of fiscal stimulus, where an increase in interest rates is delayed, quite differently than the effects of fiscal consolidation, where a decrease of interest rates is fully prevented.

Yet, purely empirical analyses of fiscal consolidation are inherently difficult because policy actions that lead to permanent changes in debt-to-GDP ratios are difficult to identify. Moreover, it is very hard to differentiate between the effects of different fiscal instruments. Accordingly, empirical papers come to opposing results regarding the output effects of fiscal consolidation. Giavazzi and Pagano (1990, 1996) and Alesina and Ardagna (2010) find that consolidation is expansionary even in the short run, while others (see e.g. Perotti, 2012; Jordà and Taylor, 2013; Guajardo et al., 2014) find that consolidation leads to a short-run output contraction.

We contribute to the literature by providing a systematic analysis of fiscal consolidation using a dynamic general equilibrium (DGE) model. This setup—in contrast to purely empirical papers—allows us to analyze various well defined scenarios. We can differentiate between the effects of different fiscal instruments by using one instrument at a time to consolidate government

finances, while holding the others constant. In particular, we study fiscal consolidation via government consumption, government investment, transfers and taxes on consumption, labor and capital. Of course, the reliability of our results depends on whether the transmission channels in our model reflect reality. Therefore, we use a medium-scale DGE model with a number of frictions which provides a framework that is able to replicate many empirically observed business cycle dynamics. Specifically, the inclusion of a share of credit-constrained households as well as a detailed fiscal sector allow for a concise analysis of fiscal policy transmission.

We calibrate the model to the US economy along the empirical estimates of Drautzburg and Uhlig (2011). Our simulations start from a debt-to-GDP ratio of 70 percent which is the empirical average in the US from 1995 to 2013. We simulate a reduction of the debt-to-GDP ratio of 10 percentage points to return to the average pre-crisis level from 1995 to 2007. Fiscal instruments react via fiscal feedback rules to the discrepancy between the actual and the targeted debt-to-GDP ratio.[1] In particular, expenditures decrease and tax rates increase to reduce the debt-to-GDP ratio. Once the debt-to-GDP ratio has been reduced, this decreases the interest rate payments of the government and creates additional fiscal leeway in the long run. The simulations are run under perfect foresight which implies that households and firms anticipate not only the consolidation path but also the usage of additional long-run fiscal space and optimize their plans accordingly.

For the transmission of fiscal policy three aspects turn out to be very important. First, the short-run output effects depend crucially on how specifically a fiscal instrument affects demand. While all fiscal instruments affect the budget constraints of households and thus consumption and investment, fiscal consolidation via government consumption and investment additionally reduces the government spending component of GDP directly. Second, the interaction of the fiscal instruments with private production factors matters. We find that short-run output costs are largest for consolidation via government investment and taxes on labor and capital because the former reduces the public capital stock which enters the private production function and in turn lowers productivity of private factors, while the latter two increase tax distortions. In all three cases the private or public capital stock decreases for some time which leads to a very persistent short- to medium-run output reduction. For consolidations via government consumption, transfers and the consumption tax rate, capital does not decrease and output recovers much faster from its short-run contraction. Differences in short-run output costs between the fiscal instruments are amplified because the more negative an instrument affects output, the larger is the adjustment of that instrument in order to ensure a decrease in the debt-to-GDP ratio to compensate the output contraction. Third, the presence of credit-constrained households matters and fiscal consolidation has large distributional consequences between credit-constrained and optimizing households. Consumption of credit-constrained households drops directly if their budget constraint tightens because of lower transfers, higher labor taxes or reductions in hours worked caused by lower production. Optimizing households, by contrast, can smooth

[1] In an earlier version of this paper (Schwarzmüller and Wolters, 2014, available from the authors upon request) we include simulations where the fiscal instruments are adjusted exogenously and permanently, while the debt-to-GDP ratio adjusts endogenously. In that version additional fiscal space is used to either increase transfers or decrease the labor tax rate in the long run. The main results are, however, very similar to the setup of this paper where the debt-to-GDP target changes exogenously and fiscal instruments adjust endogenously via feedback rules.

consumption so that their demand changes less abruptly. Hence, in the short run fiscal consolidation affects the consumption of credit-constrained households much more negatively than of optimizing households. In the long run, credit-constrained households benefit most from fiscal consolidation. Additional fiscal space leads to higher long-run income via lower taxes, increases in transfers or increases in labor income due to the increased demand and production. In the case of credit-constrained households these increases in income are used completely for consumption. By contrast, optimizing households need to split up additional income into consumption and investment to support a higher capital stock that is needed to achieve an increase in production in the new steady state.

Currently many governments do not only face high debt-to-GDP ratios. Due to the widespread phenomenon of low economic growth in the aftermath of the global financial crisis the ZLB on nominal interest rates has become binding. With our model we can analyse how the transmission of fiscal consolidation changes if monetary policy cannot accommodate fiscal consolidation measures. To do so we simulate a large recession similar to Christiano et al. (2011) to obtain a binding ZLB on nominal interest rates and combine this scenario with fiscal consolidation via different fiscal instruments. The short-run output costs increase for two reasons. First, the real interest rate increases so that output contracts more. Second, this makes a larger adjustment of the fiscal instruments necessary to reduce the debt-to-GDP ratio. We find that the amplification of the short-run output costs through the ZLB is much stronger for expenditure than for revenue based consolidations. However, overall the instruments that lower productivity and increase tax distortions still have the most negative short-run output effects.

While the policy debate on fiscal stimulus and fiscal consolidation mainly focuses on the size of the fiscal multiplier, from an economic point of view the effects on welfare are at least equally important. According to our analysis, ranking the different fiscal consolidation strategies based on their welfare impact, leads to substantially different results than ranking them based on their output effects. Generally, the welfare effects of the various fiscal consolidation instruments depend on the paths of consumption and leisure during the transition and the final steady state. As an example, consider a consolidation scenario with transfer cuts. If transfers are reduced to bring down the debt-to-GDP ratio, the short-run output reduction is small, but the consumption of credit-constrained households is highly negatively affected in the short-run which leads to a large reduction in welfare of these during the transition to the final steady state. Hence, one cannot simply derive conclusions regarding welfare from the literature on fiscal multipliers. Instead, additional welfare analysis is necessary.

The most important fiscal instrument in the discussion on the size of the fiscal multiplier is government consumption (see e.g. Cogan et al., 2010) which is why we study the effects of a government consumption based fiscal consolidation in more detail. We find that the effects depend crucially on whether government consumption provides utility to households as a substitute or complement to private consumption. In particular, if private and public consumption goods are complements then the short-run output costs and the long-run benefits increase substantially. However, if private and public consumption goods are substitutes, the short-run output costs decrease strongly because private consumption increases to substitute for the decrease in public consumption.

There are several other papers that are related to our analysis. For example, Coenen et al. (2008) simulate fiscal consolidation in the euro area using a two-country model for the euro area and the US. While they analyse one instrument at a time, Cogan et al. (2013a,b) study consolidation plans for the US that combine expenditure reductions by means of government consumption and transfer payment cuts with reductions in distortionary taxes relative to a baseline scenario of no consolidation. Incentives to work increase so that hours and income increase in the long run. Consumption even increases in the short run because households anticipate these developments and smooth consumption over time. Similarly, Forni et al. (2010) find that consolidation combined with permanent tax cuts is optimal because it has expansionary effects in the short and long run. Erceg and Lindé (2013) study the effects of fiscal consolidation in a currency union and when the ZLB on interest rates is binding. In both cases monetary policy cannot freely adjust the interest rate downwards which is why the short-run costs of fiscal consolidation increase.[2]

In contrast to the above mentioned papers, we do not only study specific aspects of fiscal consolidation but rather provide a comprehensive analysis. Having one coherent framework makes the output and welfare effects of consolidation via different instruments with and without ZLB constraint directly comparable. While many of the above papers set their focus on the quantitative effects of fiscal consolidation, we provide in addition a detailed account of the specific transmission channels of fiscal consolidation via different fiscal instruments. Further, even though we study all fiscal instruments separately to clearly distinguish their respective short- and long-run effects on output and welfare, we conclude from our results that it is optimal to consolidate via instruments with relatively low short-run output costs—such as government consumption, transfers and the consumption tax rate—and use the therewith obtained long-run fiscal space for increases in government investment and labor and capital tax cuts, which provide the largest long-run benefits. Additionally, our analysis allows to account for the welfare and the distributional consequences when setting up a specific fiscal consolidation policy mix.

The remainder of the paper is structured as follows. Section 2 provides a description of the model. Section 3 derives the long-run effects of fiscal consolidation. Section 4 studies the short-run transmission. In section 5 we analyze how the results change when the ZLB on nominal interest rates is binding. Section 6 presents the welfare analysis. Finally, section 7 concludes.

2 A New Keynesian model with a fiscal sector

In this section we provide an overview about the main model features. The model is a closed economy medium-scale DGE model. In addition to standard features like nominal frictions and real rigidities the model includes a detailed fiscal sector and credit-constrained households.

[2]The above mentioned papers are closest to our analysis. Other papers study additional aspects of fiscal consolidation. For example Corsetti et al. (2013), Roeger and in 't Veld (2013) and Philippopoulos et al. (2014) analyze the effects of fiscal consolidation on sovereign risk premia, Stähler and Thomas (2012) include cuts in public employment and wages in the analysis, Angeloni et al. (2014) study combined exit strategies from post-crisis fiscal and monetary accommodations and account for their effects on financial stability, in 't Veld (2013) focusses on differences between euro area periphery and core countries, Almeida et al. (2013) study small open economy aspects and welfare effects in an overlapping-generations model and Carvalho and Martins (2011) study under which circumstances fiscal consolidation is expansionary.

The introduction of credit-constrained households leads to non-Ricardian effects of fiscal policy. Overall, the model consists of two household types, intermediate goods producers, a representative final good producer, a central bank and a fiscal authority. The decision problems of these agents are described in the following.

2.1 Households

There is a continuum of households indexed by $j \in [0,1]$. A share of $1-\zeta$ of these households indexed by $o \in [0, 1-\zeta]$ are optimizing households. They make forward looking decisions and have access to financial markets. The lifetime utility function of each of these optimizing households o is given by:

$$E_t \sum_{s=0}^{\infty} \beta^s \left(ln(\tilde{C}_{o,t+s} - h\tilde{C}^*_{o,t+s-1} - \psi_t) - \chi \frac{N_{o,t+s}^{1+\eta}}{1+\eta} \right), \tag{1}$$

where ψ_t is a deterministic consumption demand shock which will be later used to simulate a recession and a binding ZLB on interest rates. It is assumed to follow an AR(1) process: $\psi_t = \rho^{\psi}\psi_{t-1} + \epsilon_t^{\psi}$. The parameter h determines the degree of external habit formation with respect to the aggregate peer group consumption bundle $\tilde{C}^*_{o,t+s-1}$.[3] The weight parameter χ is used to pin down the steady state level of labor supply $N_{o,t+s}$.

As in Coenen et al. (2013) we include the possibility that government consumption provides utility to households. Therefore, $\tilde{C}_{o,t+s}$ is a household specific consumption bundle consisting of consumption of private goods $C_{o,t}$ and government consumption $C_{G,t}$:

$$\tilde{C}_{o,t} = \left(\kappa_c^{\frac{1}{\nu}} C_{o,t}^{\frac{\nu-1}{\nu}} + (1-\kappa_c)^{\frac{1}{\nu}} C_{G,t}^{\frac{\nu-1}{\nu}} \right)^{\frac{\nu}{\nu-1}}. \tag{2}$$

κ_c denotes the share of government consumption in the consumption bundle and $\nu > 0$ measures the degree of substitution between private and public consumption.

Optimizing households face the following period t budget constraint:

$$\begin{aligned}(1+\tau_t^c)C_{o,t} + I_{o,t} + \frac{B_{o,t}}{P_t} = (1-\tau_t^n)\frac{W_{o,t}}{P_t}N_{o,t} + \left[(1-\tau_t^k)r_t^k u_t + \tau_t^k \delta(u_t)\right] K_{o,t-1} \\ + R_{t-1}\frac{B_{o,t-1}}{P_t} + TR_{o,t} + Div_{o,t}.\end{aligned} \tag{3}$$

They decide on the holdings of nominal government bonds $B_{o,t}$, the accumulation of physical capital $K_{o,t}$, and the amount of consumption $C_{o,t}$ and investment $I_{o,t}$. Furthermore, optimizing households choose the degree of capital utilization u_t. Optimizing households receive wage income $W_{o,t}N_{o,t}$, dividend payments from the firms $Div_{o,t}$ and lump-sum transfers from the government $TR_{o,t}$. They need to pay taxes on consumption τ_t^c, labor income τ_t^n and capital income τ_t^k. Capital income taxes are levied on capital income net-of-depreciation as in Prescott (2002, 2004) and Trabandt and Uhlig (2011). The effective amount of capital services which is

[3] Marginal utility of income is identical across optimizing households, because household members pool their wage income. Therefore, $\tilde{C}_{o,t+s} = \tilde{C}^*_{o,t+s}$ holds in equilibrium.

rent out to firms is:

$$K_{eff,o,t} = u_t K_{o,t-1}. \tag{4}$$

The capital accumulation equation is given by:

$$K_{o,t} = (1-\delta(u_t))K_{o,t-1} + \iota_t \left[1 - S_t\left(\frac{I_{o,t}}{I_{o,t-1}}\right)\right] I_{o,t}, \tag{5}$$

where ι_t is a deterministic investment technology shock which will later be used in combination with the preference shock to simulate a recession. It is assumed to follow the AR(1)process: $\frac{\iota_t}{\iota} = (\frac{\iota_{t-1}}{\iota})^{\rho_\iota} exp(\epsilon_t^\iota)$. Following Christiano et al. (2005), we assume that it is costly to adjust gross investment. The investment adjustment cost function takes the form:

$$S_t\left(\frac{I_{o,t}}{I_{o,t-1}}\right) = \frac{\kappa}{2}\left[\frac{I_{o,t}}{I_{o,t-1}} - 1\right]^2. \tag{6}$$

Capital depreciates with a rate $\delta(u_t)$. The depreciation rate is time varying and depends on deviations of the capital utilization rate from its steady state level $u = 1$. The specific functional form is quadratic and similar to Leeper et al. (2010):

$$\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \frac{\delta_2}{2}(u_t - 1)^2. \tag{7}$$

Maximizing the utility function with respect to $C_{o,t}$, $B_{o,t}$, $K_{o,t}$, $I_{o,t}$ and u_t subject to the above constraints leads to the following first order conditions:

$$\lambda_{o,t} = \kappa_c^{\frac{1}{\nu}} \left(\frac{\tilde{C}_{o,t}}{C_{o,t}}\right)^{\frac{1}{\nu}} \frac{(\tilde{C}_{o,t} - h\tilde{C}^*_{o,t-1} - \psi_t)^{-1}}{(1+\tau_t^c)}, \tag{8}$$

$$\lambda_{o,t} = \beta E_t \lambda_{o,t+1} \frac{R_t}{\Pi_{t+1}}, \tag{9}$$

$$Q_t = \beta E_t \frac{\lambda_{o,t+1}}{\lambda_{o,t}} \left[(1-\tau^k_{t+1})u_{t+1}r^k_{t+1} + \tau^k_{t+1}\delta(u_{t+1}) + Q_{t+1}(1-\delta(u_{t+1}))\right], \tag{10}$$

$$1 = Q_t\, \iota_t \left[1 - S_t\left(\frac{I_{o,t}}{I_{o,t-1}}\right) - \frac{\partial S_t}{\partial I_{o,t}} I_{o,t}\right] - \beta E_t \frac{\lambda_{o,t+1}}{\lambda_{o,t}} Q_{t+1}\, \iota_{t+1}\, \frac{\partial S_{t+1}}{\partial I_{o,t}} I_{o,t+1}, \tag{11}$$

$$Q_t \delta'(u_t) = (1-\tau^k_t) r^k_t + \tau^k_t \delta'(u_t), \tag{12}$$

where $\lambda_{o,t}$ is the Lagrange multiplier on the budget constraint, Q_t is Tobins's Q and Π_{t+1} is the gross inflation rate.

A share ζ of the households indexed by $r \in [1-\zeta, 1]$ are credit-constrained households, which do not have access to financial markets so that the budget constraint involves less terms than for optimizing households:

$$(1+\tau^c_t)C_{r,t} = (1-\tau^n_t)\frac{W_{r,t}}{P_t} N_{r,t} + TR_{r,t}. \tag{13}$$

Credit-constrained households have the same utility function as optimizing households. In each period they, however, fully consume their current labor income and the transfers received from the government because they cannot smooth consumption as they do not have access to the bond market and cannot invest in physical capital.

2.2 Wage setting

As in Erceg et al. (2000), we assume that each household is a monopolistic supplier of differentiated labor services $N_{i,t}$. The household sells this labor service to a representative firm that bundles all labor services into an aggregate labor service N_t via:

$$N_t = \left(\int_0^1 N_{i,t}^{\frac{\theta_w - 1}{\theta_w}} \, di \right)^{\frac{\theta_w}{\theta_w - 1}}. \tag{14}$$

The demand for $N_{i,t}$ is given by:

$$N_{i,t} = \left(\frac{W_{i,t}}{W_t} \right)^{-\theta_w} N_t, \tag{15}$$

where W_t is the aggregate wage index, which is defined as:

$$W_t = \left(\int_0^1 W_{i,t}^{1-\theta_w} \, di \right)^{\frac{1}{1-\theta_w}}. \tag{16}$$

Optimizing households set nominal wages in staggered contracts. Every period, there is a probability of $1 - \omega_w$ that each household member is allowed to re-optimize the wage. If a household member is not allowed to set the wage optimally it is simply indexed to inflation in period $t-1$:

$$W_{o,t} = W_{o,t-1} \left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_w}, \tag{17}$$

where γ_w is the parameter defining the degree of indexation.

When an optimizing household is allowed to reset the wage $W_{o,t}$ is chosen to maximize the intertemporal utility function (1) subject to the intertemporal budget constraint (3) and the labor demand equation (15). The resulting first order condition is:

$$E_t \sum_{k=0}^{\infty} (\beta \omega_w)^k \left[(1 - \tau_{t+k}^n) \frac{W_{o,t}^*}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\gamma_w} - \frac{\theta_w}{\theta_w - 1} (1 + \tau_{t+k}^c) MRS_{o,t+k} \right] \lambda_{o,t+k} N_{o,t+k} = 0, \tag{18}$$

where $W_{o,t}^*$ denotes the optimal wage set in period t and $MRS_{o,t+k} \equiv -\frac{\partial U_{o,t+k}/\partial N_{o,t+k}}{\partial U_{o,t+k}/\partial C_{o,t+k}}$ denotes the marginal rate of substitution between consumption and hours worked.

As in Erceg and Lindé (2013) we assume that credit-constrained households set their wage equal to the average wage rate of the optimizing households. Because both household types face the same labor demand schedule this assumption implies that the demand for labor is equally

distributed between household types, $N_{o,t} = N_{r,t} = N_t$. For a discussion of alternative wage-setting schemes for credit-constrained households the reader is referred to Furlanetto (2011).

The definition of the aggregate wage index in equation (16) implies, that the law of motion for the wage index is given by:

$$W_t^{1-\theta_w} = (1-\omega_w)(W_t^*)^{1-\theta_w} + \omega_w \left(\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_w} W_{t-1} \right)^{1-\theta_w}. \tag{19}$$

2.3 Firms

The production side of the economy consist of an intermediate goods sector and a final good sector.

2.3.1 Final good sector

In the final good sector, a representative retail firm bundles intermediate products $y_{j,t}$ into a composite final good Y_t using a CES aggregator:

$$Y_t = \left(\int_0^1 y_{j,t}^{\frac{\theta_p - 1}{\theta_p}} dj \right)^{\frac{\theta_p}{\theta_p - 1}}. \tag{20}$$

Given the price $p_{j,t}$ of the intermediate inputs, the retail firm chooses intermediate good inputs $y_{j,t}$ to minimize the costs of producing Y_t. This cost minimization problem yields the demand function for each variety of the intermediate input:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t} \right)^{-\theta_p} Y_t. \tag{21}$$

Perfect competition in the final good market implies that the retail firm sells each unit of output at price P_t:

$$P_t = \left(\int_0^1 p_{j,t}^{1-\theta_p} dj \right)^{\frac{1}{1-\theta_p}}. \tag{22}$$

2.3.2 Intermediate goods sector

There is a continuum of differentiated intermediate goods producers, indexed by $j \in [0,1]$. Each firm j produces output with a Cobb-Douglas production function,

$$y_{j,t} = z_t K_{G,t-1}^{\kappa_k} K_{eff,j,t}^{\alpha} N_{j,t}^{1-\alpha} - \Phi, \tag{23}$$

where $K_{eff,j,t}$ and $N_{j,t}$, denote effective capital and labor employed by the firm. The parameter α defines the elasticity of output with respect to private capital. Following Baxter and King (1993), $K_{G,t-1}$ is the public capital stock available in period t, and κ_k is the elasticity of output with respect to public capital. Φ are fixed costs of production. Finally, z_t is aggregate total factor productivity.

Intermediate goods firms buy factor inputs in perfectly competitive markets. Let w_t and r_t^k

denote the real wage rate and the rental rate of capital. Cost minimization implies that real marginal costs are given by

$$mc_t = \frac{1}{z_t \, K_{G,t-1}^{\kappa_k}} (r_t^k)^{\alpha} w_t^{1-\alpha} \frac{1}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}}, \tag{24}$$

which are identical across firms.

Intermediate goods firms sell their products under monopolistic competition. In every period each firm faces the constant probability $1-\omega_p$ of being allowed to re-optimize its price $p_{j,t}$. If a firm is not allowed to set its price optimal in period t we assume that a firm indexes its price to last period's inflation $p_{j,t} = \left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p} p_{j,t-1}$, with the parameter γ_p defining the degree of indexation. If a firm is allowed to set the optimal price in period t it maximizes

$$E_t \sum_{k=0}^{\infty} (\omega_p \beta)^k \frac{\lambda_{o,t+k}}{\lambda_{o,t}} \left[\frac{p_{j,t}}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\gamma_p} - mc_{t+k} \right] y_{j,t+k} \tag{25}$$

taking the demand for its products as given. The resulting first order condition is

$$E_t \sum_{k=0}^{\infty} (\omega_p \beta)^k \frac{\lambda_{o,t+k}}{\lambda_{o,t}} \left[\frac{p_{t,j}^*}{P_{t+k}} \left(\frac{P_{t+k-1}}{P_{t-1}} \right)^{\gamma_p} - \frac{\theta_p}{\theta_p - 1} mc_{t+k} \right] y_{j,t+k} = 0, \tag{26}$$

where $p_{t,j}^*$ is the optimal price set in period t.

The definition of the aggregate price index in equation (22) implies, that the law of motion for the price index is given by:

$$P_t^{1-\theta_p} = (1-\omega_p)(p_{t,j}^*)^{1-\theta_p} + \omega_p \left(\left(\frac{P_{t-1}}{P_{t-2}} \right)^{\gamma_p} P_{t-1} \right)^{1-\theta_p}. \tag{27}$$

2.4 Monetary policy

We assume that the central bank follows a Taylor type rule to set the nominal interest rate R_t:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left[\left(\frac{\Pi_t}{\Pi} \right)^{\delta_\pi} \left(\frac{Y_t}{Y_{f,t}} \right)^{\delta_y} \right]^{(1-\rho_R)}, \tag{28}$$

where $Y_{f,t}$ is the flex-price output level. The parameter ρ_R determines the degree of interest rate smoothing, whereas the parameters δ_π and δ_y determine the response to the deviations of inflation from its steady state value and the output gap.

2.5 Fiscal policy

The government budget constraint in real terms is:

$$b_t + \tau_t^n w_t N_t + \tau_t^c C_t + \left[u_t r_t^k - \delta(u_t) \right] \tau_t^k K_{t-1} = C_{G,t} + I_{G,t} + TR_t + \frac{R_{t-1}}{\Pi_t} b_{t-1}. \tag{29}$$

$b_t = \frac{B_t}{P_t}$ denotes the end of period t stock of government debt. Government spending consists of public consumption $C_{G,t}$, public investment $I_{G,t}$ and transfers TR_t to households. On the

revenue side the government raises taxes on private consumption τ_t^c as well as on labor income τ_t^n and capital income τ_t^k.

The public capital stock evolves as

$$K_{G,t} = (1 - \delta_G)K_{G,t-1} + \left[1 - S_{G,t}\left(\frac{I_{G,t}}{I_{G,t-1}}\right)\right] I_{G,t}, \tag{30}$$

where δ_G is the depreciation rate and $S_{G,t}\left(I_{G,t}/I_{G,t-1}\right)$ is an adjustment cost function, which has the same functional form as the adjustment cost function for the accumulation of physical private capital.

The fiscal instruments adjust endogenously according to a fiscal rule to ensure convergence to the steady state. For the expenditure instruments we define the linear rule (31) and for the revenue instruments we define the linear rule (32):

$$x_t - x_{t-1} = -\phi_0\left(bY_{t-1} - bY_{target}\right) - \phi_1\left(bY_{t-1} - bY_{t-2}\right), \tag{31}$$

$$s_x\left(\tau_t^x - \tau_{t-1}^x\right) = \phi_0\left(bY_{t-1} - bY_{target}\right) + \phi_1\left(bY_{t-1} - bY_{t-2}\right). \tag{32}$$

$x_t = \frac{X_t}{Y}$ denotes the share of the expenditure instrument relative to initial steady state output, where $X_t = \{C_{G,t}, I_{G,t}, TR_t\}$. $s_x = \frac{S^x}{Y}$ denotes the initial steady state tax base of the revenue instrument relative to GDP, where $S^x = \{C, wN, (r^k - \delta_0)K\}$ and $\tau_t^x = \{\tau_t^c, \tau_t^n, \tau_t^k\}$. The expenditure and the revenue instruments react to the deviation of the debt-to-GDP ratio $bY_{t-1} = \frac{b_t}{4\,Y_t}$ from its long-run target bY_{target} and the change in the debt-to-GDP ratio. If the debt-to-GDP ratio is above its target, this leads to a reduction of government expenditures (see equation (31)) or to an increase in tax rates (see equation (32)). The parameter ϕ_0 determines how large these adjustments are. The reaction to the change in the debt-to-GDP ratio ensures that fiscal instruments are adjusted smoothly. The smoothness is controlled by the parameter ϕ_1.

2.6 Calibration

In calibrating the model we mainly rely on estimates from Drautzburg and Uhlig (2011). They estimate a closed economy DSGE model similar to ours using US data from 1947 to 2009 with Bayesian techniques. We use estimates for the US as our simulation exercise mirrors the US case more closely than for example consolidation efforts of countries in the euro area. Some of these countries have experienced high increases in risk premia which might decrease along with fiscal consolidation. This might have additional positive effects on GDP which are not captured by our model. While the US debt-to-GDP ratio is increasing and thus fiscal consolidation is an important topic, risk premia have not risen substantially yet, so that our model framework is appropriate.

Initial steady state tax rates are taken from Trabandt and Uhlig (2011). They use the methodology from Mendoza et al. (1994) to calculate average effective tax rates. Based on data from 1995 to 2007 the consumption tax rate is set to 5 percent, the labor tax rate to 28 percent and the capital tax rate to 36 percent. The calibration of the tax rates is important for the results with respect to Laffer curve effects. Trabandt and Uhlig (2011) show that for the US

these tax rates are on the left hand side of the labor and capital tax Laffer curves in a neoclassical growth model with steady state characteristics roughly similar to the our model. An increase in these tax rates will therefore increase tax revenues. For the consumption tax rate they do not find a peak of the Laffer curve so that consumption tax rate hikes will lead to rising tax revenues, too. The slope of the Laffer curve does not change much for a range of about 20 to 40 percent for the labor tax rate and about 0 percent to 50 percent for the capital tax rate so that the results should also give some indication for the effects of fiscal consolidation for somewhat different initial steady state tax rates.

Drautzburg and Uhlig (2011) obtained time averages of government spending components from NIPA table 3.1. Accordingly, we calibrate spending on government consumption to 15.22 percent (this includes the value for net exports) and spending on government investment to 4 percent of GDP. The initial steady state transfer-to-GDP ratio is implied by the government budget constraint in equation (29) and amounts to 6.95 percent of GDP which is close to the actual value of 8.47 percent in the sample used by Drautzburg and Uhlig (2011). The share of credit-constrained households is set to $\zeta = 0.25$. Overall transfers are split up between household types according to their share in the population. In consequence, consumption levels differ in steady state. In our setup the consumption of credit-constrained households amount to 87 percent of the consumption of optimizing households.

The parameters of the fiscal policy rule are set to $\phi_0 = 0.0125$ and $\phi_1 = 0.25$. These parameter values lead to a smooth transition of the stabilizing instrument and the debt-to-GDP ratio to the long-run equilibrium. The efficiency of public capital is set to $\kappa_k = 0.05$ as in Baxter and King (1993). The depreciation rate of public capital is equal to the steady state depreciation rate of private capital ($\delta_0 = \delta_G = 0.0145$) as in Drautzburg and Uhlig (2011).

The inverse of the labor supply elasticity equals 2.16 which is consistent with microeconomic estimates (Chetty et al., 2011) and the intratemporal elasticity of substitution is set to one so that we have a log utility specification. We set the discount factor $\beta = 0.995$, which implies an annualized steady state nominal interest rate of 2 percent. We choose this rather low nominal interest rate in order to push the economy more easily to the zero lower bound on nominal interest rates. Steady state gross inflation is $\Pi = 1$ so that there is no price dispersion in steady state. There are adjustment costs for private capital, $\kappa = 4.51$, and for public capital, $\kappa_G = 7.11$, as estimated by Drautzburg and Uhlig (2011). We set the parameter δ_1 equal to the steady state rental rate of capital to ensure that capacity utilization equals unity in steady state. The value $\delta_2 = 0.29$ is an estimate taken from Leeper et al. (2010). An overview about all parameters can be found table 1.

2.7 Consolidation scenario

We start all simulations from an initial steady state debt-to-GDP ratio of 70 percent which is about the average US debt-to-GDP ratio from 1995 to 2013. We adjust the fiscal instruments in a way that the debt-to-GDP ratio is reduced to 60 percent which is the average debt-to-GDP ratio from 1995 to 2007.

We run six consolidation scenarios, one for each of the six fiscal instruments. In each scenario

Table 1: Calibrated parameters

Parameter	Value
Discount factor β	0.995
Intratemporal elasticity of substitution σ	1
Weight of private consumption in the utility function κ_c	1
Inverse of Frisch labour elasticity η	2.16
Degree of habit formation h	0.80
Share of credit-constrained households ζ	0.25
Steady state labor N	0.30
Investment adjustment cost private capital κ	4.51
Private capital depreciation:	
δ_0	0.0145
δ_1	r^k
δ_2	0.29
Investment adjustment cost public capital κ_G	7.11
Public capital depreciation rate δ_G	0.0145
Efficiency of public capital in private production κ_k	0.05
Capital share α	0.24
Price mark-up parameter θ_p	2.06
Wage mark-up parameter θ_w	3.00
Government consumption share C_G/Y	0.1522
Government investment share I_G/Y	0.04
Transfer share TR/Y	0.0695
Consumption tax rate τ^c	0.05
Labor tax rate τ^n	0.28
Capital tax rate τ^k	0.36
debt-to-GDP ratio bY	0.70
Responsiveness of instruments to deviations from debt target ϕ_0	0.0125
Responsiveness of expenditure instruments to debt changes ϕ_1	0.25
Steady state gross inflation Π	1
Calvo price ω_p	0.81
Calvo wage ω_w	0.83
Price indexation γ_p	0.28
Wage indexation γ_w	0.41
Taylor rule inflation reaction δ_π	1.63
Taylor rule output gap reaction δ_y	0.13
Taylor rule interest rate smoothing ρ_R	0.92

we hold five instruments constant, i.e. we shut-off the fiscal rules (31) and (32) for these five instruments. For the remaining instrument we use the respective fiscal rule in equation (31) or (32). To achieve the desired debt reduction, we set the target debt-to-GDP ratio in this fiscal rule equal to 60 percent. The fiscal rule ensures that the fiscal instrument is adjusted in a way that the debt-to-GDP ratio smoothly decreases towards the target.

The first term on the right hand side of the fiscal rules ensures that the difference between the initial debt-to-GDP ratio and the target ratio leads to a reduction in government spending (equation 31) or an increase in tax rates (equation 32). The second term on the right hand side of the fiscal rules ensures that the consolidation is smoothed out over time by penalizing large period to period changes in the debt-to-GDP ratio. Once the debt-to-GDP ratio is close to the target the fiscal rules reverse the adjustment of fiscal instruments. Otherwise a permanent reduction in government spending or a permanent increase in tax revenues would lead to a

permanent surplus and a continuing decrease of the debt-to-GDP ratio. In the final steady state the level of government spending even increases slightly above the initial steady state level because there is additional fiscal space caused by the lower level of government debt which leads to lower interest rate payments compared to the initial steady state. Similarly, in the case of a tax based consolidation, in the new steady state the tax rate is reduced slightly below the initial steady state level.

We first solve for the initial steady state and then for the final steady state with the reduced debt-to-GDP ratio. Afterwards, we compute transitional dynamics between the initial and the final steady state. Here we use deterministic simulations and solve for transitional dynamics by using the stacked Fair-Taylor algorithm. This procedure has the advantage that we can work with the non-linear model. Households, firms and policy makers have perfect foresight and the paths of fiscal instruments and debt dynamics are fully anticipated. From the first simulation period onwards optimizing households and firms adjust their decisions accordingly. For the baseline simulations all dynamics are solely caused by the deviation of the initial debt-to-GDP ratio from its target and the adjustments of the considered fiscal instrument via the fiscal rule. For the analysis of fiscal consolidation at the ZLB we include additional recessionary shocks. That specific setting is discussed in detail in section 5. For the baseline simulations we further assume that government consumption does not provide utility to households. Hence, we set $\kappa_c = 1$ in equation (2). The case of $\kappa_c < 1$ will also be analyzed.

3 Long-run effects of fiscal consolidation

While the main focus of this paper certainly lies on the short- to medium-run transmission of fiscal consolidation, here we shortly discuss the long-run effects. In the long run, the economy converges to the new steady state with a reduced debt-to-GDP ratio. This implies lower interest rate payments for the government which, depending on the simulated fiscal instrument, lead either to a small increase in government expenditures or a small decrease in tax rates compared to the initial steady state. These steady state changes in fiscal instruments have effects on the steady state values of other macroeconomic variables.

3.1 Key steady state equations

Short-run nominal frictions and whether or not the transition to the new steady state includes a period of a binding ZLB on the nominal interest rate do not matter for the steady state. To understand the long-run effects it is therefore sufficient to focus on the key steady state relations. These are very similar to the steady state of a simple real business cycle (RBC) model except that our model includes monopolistic rather than perfect competition and a variety of fiscal instruments.

Households set wages in the monopolistic labor market as a mark-up over the marginal rate of substitution (MRS). The consumption tax and labor tax rate drive a further wedge between the real wage and the MRS:

$$\frac{1-\tau^n}{1+\tau^c} w = \frac{\theta_w}{\theta_w - 1} \text{MRS}. \tag{33}$$

The optimality condition for capital shows that the steady state rental rate of capital depends only on the capital tax rate, the discount factor and the steady state depreciation rate of capital:

$$r^k = \frac{\frac{1}{\beta} + \tau^k \delta_0 - 1 + \delta_0}{1 - \tau^k}. \tag{34}$$

Finally, after aggregating over all intermediate goods firms it follows that factor prices equal their respective marginal products adjusted by the inverse price mark-up:

$$w = \frac{\theta_p - 1}{\theta_p} MPL, \text{with } MPL = (1-\alpha) z K_G^{\kappa_k} \left(\frac{K}{N}\right)^{\alpha}, \tag{35}$$

$$r^k = \frac{\theta_p - 1}{\theta_p} MPK, \text{with } MPK = \alpha z K_G^{\kappa_k} \left(\frac{K}{N}\right)^{\alpha-1}. \tag{36}$$

3.2 Long-run transmission of different fiscal consolidation strategies

Table 2 shows the long-run effects of fiscal consolidation for the different instruments. Column 1 shows in each row which instrument is adjusted and the other columns show the effects on key macroeconomic variables. The long-run use of additional fiscal space due to lower interest rate payments is shown in the last column. The numbers in the table show percentage changes relative to the initial steady state except for the debt-to-GDP ratio and the tax rates where percentage point changes are reported.

Table 2: Long-run effects of fiscal consolidation for various consolidation instruments

	Y	C	$\tilde{C}$	I	N	w	r^k	C_o	C_r	ΔBy	ΔInstr.
$C_G(\kappa_c = 1)$	0.12	-0.18	-0.18	0.12	0.12	0.00	0.00	-0.27	0.11	-10.00	0.22
$C_G(\kappa_c = 0.75, \nu = 1.5)$	0.08	-0.22	0.15	0.08	0.08	0.00	0.00	-0.31	0.07	-10.00	0.21
$C_G(\kappa_c = 0.75, \nu = 0.5)$	0.33	0.00	0.58	0.33	0.33	0.00	0.00	-0.09	0.29	-10.00	0.28
I_G	0.76	0.38	0.38	0.76	0.14	0.61	0.00	0.30	0.67	-10.00	0.39
TR	0.03	0.04	0.04	0.03	0.03	0.00	0.00	-0.06	0.36	-10.00	0.21
τ^c	0.12	0.16	0.16	0.12	0.12	0.00	0.00	0.08	0.45	-10.00	-0.36
τ^n	0.16	0.20	0.20	0.16	0.16	0.00	0.00	0.11	0.53	-10.00	-0.32
τ^k	0.62	0.39	0.39	2.31	0.08	0.53	-1.66	0.35	0.55	-10.00	-3.17

Notes: τ^c, τ^n and τ^k denote consumption, labor and capital tax rates. $\nu = 1.5$ denotes the case where public and private consumption are substitutes and $\nu = 0.5$ denotes the case where they are complements. All variables are denoted in percentage changes except for ΔBy which is in percentage points. Δ Instrument is expressed as percentage change relative to initial GDP for expenditure instruments and percentage point changes for tax instruments. The steady state percentage change in the capital stock K is the same as in investment I.

Government consumption Government consumption does not show up in the above mentioned steady state relations, but in the resource constraint. In the baseline scenario (row 1, $\kappa_c = 1$) a permanent increase in government consumption absorbs resources from the economy, without providing utility to households. This induces a negative wealth effect on households, leading to a crowding-out of aggregate consumption and higher labor supply. The latter leads to an increase in the marginal product of capital (MPK), as shown in equation (36). The rental rate of capital is pinned down by equation (34) and therefore cannot adjust upwards in response to the increase in MPK. In consequence, the response of optimizing households is an increase in the steady state capital stock and investment to bring down the MPK to its initial level. Thus,

the capital-labor-ratio does not differ from the initial steady state implying no real wage changes (equation 35). Higher labor and capital inputs lead to an increase in output. The two household types are affected very differently. The crowding-out of aggregate consumption is solely caused by optimizing households. The reason is that the lower debt-to-GDP ratio leads to lower interest income from holding government bonds so that consumption is reduced. On the contrary, the labor income of credit-constrained households rises which leads to higher consumption.

Arguably, at least some subcomponents of government consumption like expenditures on education, health care or defense might provide utility to households. Therefore, we analyse now how the results change, if we set the share parameter κ_c in equation (2) to 0.75, which is in line with the existing literature (see e.g. Bouakez and Rebei, 2007, or Coenen et al., 2012). The parameter ν measures the degree of substitutability between private and public consumption. In the existing literature there is no clear consensus whether private and public consumption are substitutes or complements. Prescott (2002) argues that they are substitutes, whereas more recent estimates obtained from structural DSGE models suggest that they are complements (see e.g. Bouakez and Rebei, 2007, for the US or Coenen et al., 2012, for the euro area). Therefore we consider $\nu = 1.5$ and $\nu = 0.5$. The former implies that private and public consumption are substitutes, while the latter implies that they are complements.

For $\nu = 1.5$ output increases by only 0.08 percent compared to 0.12 percent in the baseline scenario. In case of $\nu = 0.5$ output is boosted by 0.33 percent. The reason for these differences lies in the different steady state values of consumption. In the baseline case private consumption is crowded out by government consumption. This effect is amplified if private and public consumption are substitutes because private consumption can be reduced without a loss in utility. By contrast, in the case where they are complements a decrease in private consumption in response to an increase in government consumption is prevented. On the one hand an increase in government consumption takes away resources from the economy which puts negative pressure on private consumption, but on the other hand households also want to increase private consumption to complement the increase in public consumption. Hence, the overall effect on private consumption is zero.

Government investment A permanent increase in government investment has the same negative wealth effect as government consumption (the baseline case in which government consumption does not provide utility to households). In addition, there is a positive effect stemming from the long-run increase in the public capital stock. Equations (35) and (36) show that the rise of K_G works like a productivity shift. The strength of this productivity channel depends on the productivity parameter of the public capital stock κ_K and the initial steady state share of public investment. Again, the rental rate of capital is fixed so that factor inputs need to adjust to bring down the MPK. That is, investment must increase more than hours to raise the capital-labor ratio. A higher capital-labor ratio leads to an increase in the marginal productivity of labor (MPL) and the real wage. Altogether, this results in a strong increase in long-run output and an increase in consumption for both household types.

Transfers In contrast to government consumption and investment an increase in transfers has no direct effect on GDP as transfers are not a demand component of output. They have, how-

ever, effects on private consumption and investment and impact GDP through these indirectly. Transfers increase by the additional fiscal leeway created through lower interest payments. The long-run increase in transfers is lower compared to the other expenditure instruments. Transfers do not show up in the above steady state equations and therefore do not alter any equilibrium prices or ratios. If there were no credit-constrained households, Ricardian equivalence would hold and there would be no change in output or consumption at all. The increase in transfers paid to households would exactly offset the decrease in interest income from holding government bonds. Credit-constrained households do not suffer from reduced interest rate income and use the increase in transfers for consumption. Consequently, output increases slightly to satisfy additional demand. The MRS is unaffected so that the wage set by households does not change. Firms demand more labor to produce more output. The consumption of optimizing households falls slightly due to the reduction in their income from holding government bonds. This reduction is not fully compensated through the increase in transfers since a share of the additional transfers is given to the credit-constrained households. The rental rate of capital stays constant according to equation (34) so that capital adjusts upwards until the pre-consolidation capital-labor ratio is restored.

Consumption tax rate A long-run decrease of the consumption tax rate makes consumption relative to leisure less expensive. This shifts the MRS upwards without affecting the wage or the rental rate of capital as can be seen from equations (33) and (34). Consumption increases because households can afford more consumption goods for a given level of income. The additional demand leads to an increase in output. The factor inputs increase proportionally as their ratio remains unchanged to ensure that the real wage and the rental rate of capital remain constant (equations (35) and (36)). The increase in hours worked leads to an increase in wage income, which further amplifies the increase in consumption. Overall, all variables except for private and public consumption converge to nearly the same level as in the government consumption based consolidation scenario.

Labor tax rate A decrease in the labor tax rate leads to a higher after-tax income and increases incentives to work. The opportunity costs of leisure relative to consumption increase. Households want to consume more and enjoy less leisure which changes the MRS without altering the pre-tax wage. The rental rate of capital does not change as can be seen in equation (34). Therefore, the capital intensity does not change. Labor, capital and therefore also output increase by the same amounts and consumption goes up as households have more wage income available.

Capital tax rate A decrease in the capital tax rate lowers the rental rate of capital via equation (34). The usage of capital becomes cheaper. This reduction in capital tax distortions leads to an increase of capital in production and raises the capital-labor-ratio according to equation (36). In turn, the marginal product of labor increases according to equation (35). In response the real wage and the MRS adjust via equation (33). Output, consumption, investment and hours worked increase. The increase of investment is much larger than the increase of hours worked in order to equate the MPK to the new long-run rental rate of capital. The increase

in output is much higher than for the labor and consumption tax rate scenarios. The capital tax base is small so that a large decrease in the capital tax rate is necessary to stabilize the debt-to-GDP ration at the debt-neutral level. Hence, the capital stock and output increase a lot.

3.3 Comparison of long-run output benefits

All considered fiscal consolidation strategies yield long-run output benefits. The extent of these benefits, however, varies widely from an increase in output of 0.03 percent to 0.76 percent. Government investment has the largest effect on output, because it increases the productivity of both labor and capital. The second largest output expansions are achieved by capital and labor tax cuts which both reduce tax distortions. The output effects of the capital tax rate cut are, however, much higher than the ones of the labor tax rate cut. A reduction in the consumption tax rate and an increase in government consumption (baseline calibration) raise output via an increase in demand either for private or public consumption. The effect on output triples if public consumption is utility enhancing and complementary to private consumption. It decreases somewhat in the substitution case. By contrast to all these scenarios, an increase in transfers has almost no effect on output. In a model without credit-constrained households the effect would be exactly zero, while in our model output slightly increases via the increase in consumption of credit-constrained households.

These differences, in long-run effects are also important for the short- to medium-run transmission of fiscal policy because households and firms anticipate these long-run developments and adjust their planning already in the short run accordingly as will be shown in the next section.

4 Short-run transmission of fiscal consolidation without zero lower bound constraint

In this section we analyse the short- to medium-run effects of fiscal consolidation, i.e. the transitional dynamics between the initial and the final steady state.

4.1 Transmission of a government consumption based consolidation

The transmission of a government consumption based consolidation is shown in figure 1. We focus first on the *solid lines*, which show the baseline case in which government consumption does not provide utility ($\kappa_c = 1$). The plot for government consumption shows that it is reduced for about 20 quarters to generate a government surplus and the debt-to-GDP ratio falls accordingly. Afterwards, government consumption starts increasing, but stays below its initial steady state for about another 30 quarters. Hence, the debt-to-GDP ratio continues to fall until it finally converges to the debt-to-GDP target of 60 percent.

Government consumption is a component of aggregate demand. Therefore, the reduction in government consumption has a direct negative effect on output. The debt-to-GDP ratio stays more or less constant during the first year despite the cuts in government expenditures because output decreases and labor tax revenues fall due to the reduced tax base. The fiscal rule (31)

ensures that government consumption is reduced sufficiently, so that despite this negative effect on output the debt-to-GDP ratio starts to fall after some time.

The drop in output is smaller than the overall reduction in government consumption because of an increase in private consumption. The immediate expansion in consumption is solely due to the behavior of optimizing households who want to smooth their consumption path. They anticipate an income increase because of the inflow of funds stemming from the repayment of government debt holdings and accordingly they start to consume more. Due to the consumption habit friction the increase in consumption takes a while. In the long run, however, consumption of optimizing households is below its initial steady state (see table 2). Nevertheless, consumption increases temporarily because the transition to the final steady state takes so long that it is largely discounted. The temporary wealth effect caused by the repayment of debt does not only lead to an increase in consumption, but also to a decrease in hours worked. This leads to a fall in labor income, which is identical for optimizing and credit-constrained households and forces the latter to consume less. Their consumption is below the initial level for around 20 quarters. Optimizing households use debt repayments that they do not use for consumption to build up the capital stock in anticipation of the long-run increase in output. Initially investment rises only slowly because of the investment adjustment costs. As the increase in capital is not needed on the production side in the beginning of the consolidation the capital utilization rate falls.

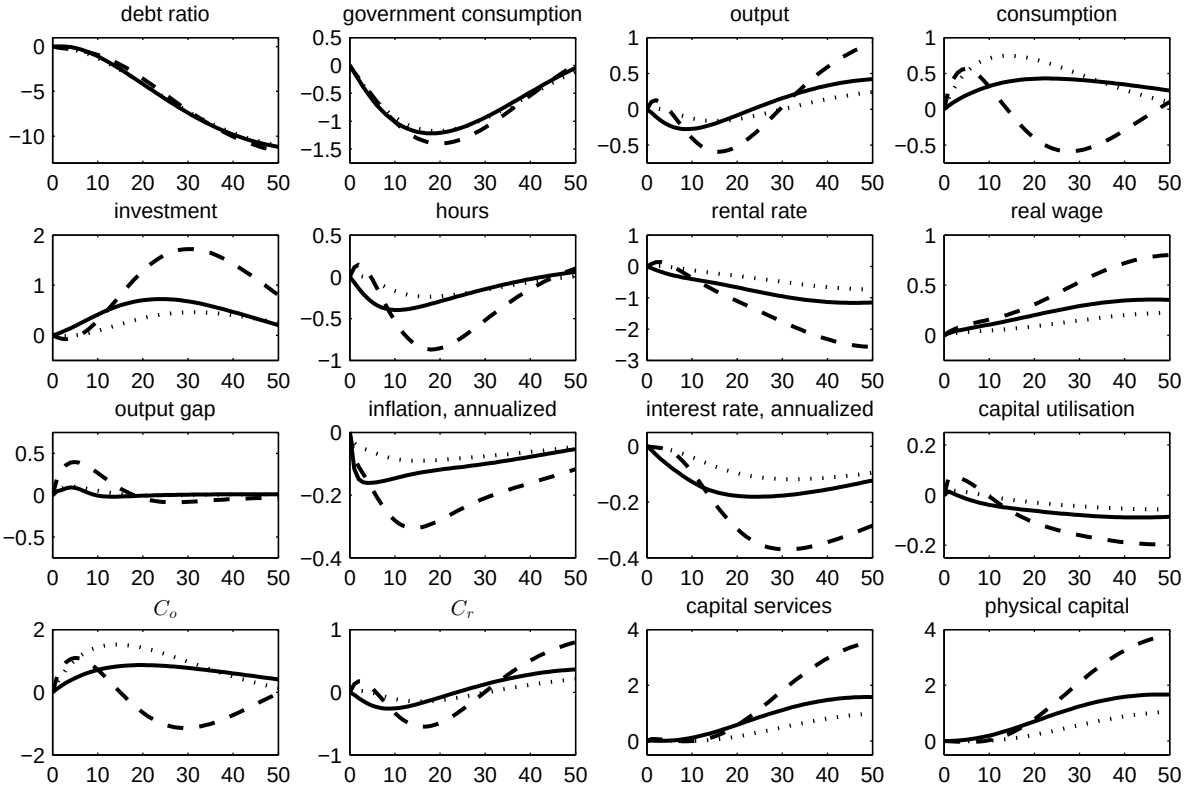

Figure 1: Transmission of consolidation via government consumption.
Notes. *Solid line: baseline, dashed line: complements, dotted line: substitutes.* Debt-to-GDP ratio, inflation and the interest rate are denoted in percentage point changes. Consumption and investment are weighted with their initial share of output. For the output gap level values are plotted. Government consumption is weighted with the initial output share. All other variables are plotted as percentage changes.

On the production side of the economy firms react to the lack of demand by reducing labor

input. The amount of capital services is roughly held constant during the first two years of consolidation. Labor input is reduced because optimizing households want to consume more and work less due to the temporary wealth effect. They demand a higher wage but overall the wage variation is small. The rental rate of capital decreases as the large reduction in hours worked reduces the marginal product of capital services. The movements in the output gap are very small because the perfect foresight assumption implies that firms which are able to adjust their prices in a given period incorporate all future developments when setting the optimal price. Thus, inefficiencies due to price rigidities are small. Marginal costs decrease as the decrease in the rental rate of capital is larger than the increase in wages. This puts downward pressure on inflation and leads via the monetary policy rule to a lower interest rate. The changes in inflation and the interest rate are, however, very small.

Together with the increase in consumption the increase in investment counterbalances the negative effects of government consumption on output so that after about 20 quarters output starts to rise above the initial steady state level. Accordingly, hours worked start to increase as well and the rise in labor income leads to an increase in consumption of credit-constrained households. Finally, after 50 quarters government consumption increases above the initial steady state. The full convergence to the final steady state takes with about 60 years a long time.

Utility enhancing government consumption Figure 1 also shows the cases in which government consumption provides utility to households. *Dashed lines* denote the case of complementarity ($\kappa_c = 0.75, \nu = 0.5$) and *dotted lines* the case of substitutability ($\kappa_c = 0.75, \nu = 1.5$) between private and public consumption.

The differences between the three specifications are to a large extent driven by the responses of consumption. For the case where private and public consumption are complements the wealth effect and the preference specification work into opposite directions. In the beginning the wealth effect dominates and triggers a rise in consumption of optimizing households. Once the drop in public consumption becomes large enough optimizing households start to reduce their consumption considerably.[4] As a consequence aggregate demand falls strongly. The drop in output at the recession trough is about twice as large as in the baseline scenario. This large drop leads to a strong reduction in hours worked which ceteris paribus reduces the marginal product of capital and therefore leads to a decline in the rental rate of capital. As a consequence firms demand more capital services which leads to a strong increase in investment.

For the case where private and public consumption are substitutes the expansion of private consumption is strongly amplified. The reason is that in addition to the wealth effect the reduction of government consumption leads optimizing households to increase their spending considerably. The wealth effect and the preference specification work into the same direction. The increase in private consumption almost completely offsets the reduction in government consumption so that aggregate demand falls only slightly.

[4]Note, that households want to smooth $\tilde{C}_t$ and not C_t. Hence, while the path of private consumption is wavelike, the path of $\tilde{C}_t$ (not shown) is very smooth.

4.2 Transmission of a government investment based consolidation

Figure 2 shows the short-run transmission of cuts in government investment (*black lines*). For comparison the *grey lines* show the effects of a government consumption (baseline calibration) based consolidation as discussed above.

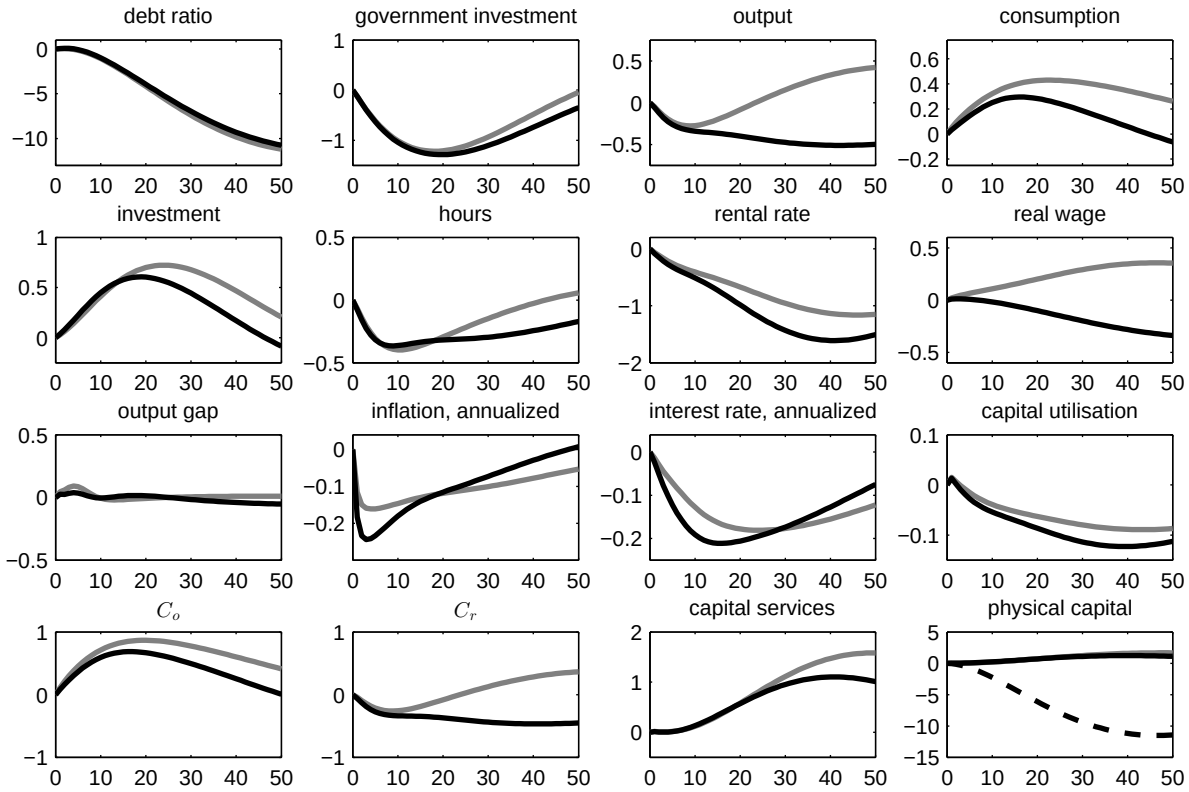

Figure 2: Transmission of consolidation via government investment (*black lines*).
Notes: See figure 1. For comparison *grey lines* show the simulation results from figure 1 (consolidation via government consumption). Government investment is weighted with the initial output share. The *dashed line* in the bottom right picture denotes the change in the public capital stock.

A consolidation via government investment would have exactly the same effects as a cut in government consumption for the case of $\kappa_k = 0$. If $\kappa_k > 0$ the induced change in the public capital stock leads to differences. The dashed line in the graph on the lower right shows the change in the public capital stock. The public capital stock decreases slowly over time. Hence, on impact the effect on private production via a reduction of the public capital stock is small. Only over time the productivity of private capital and labor is reduced substantially.

The initial negative effects are somewhat more pronounced compared to a government consumption based consolidation because optimizing households anticipate the very persistent decline in output and income and are less willing to increase consumption. By contrast, investment shows for the first couple of years almost exactly the same path as for the case of a government consumption reduction. This is because optimizing households invest in private capital to temporary substitute for public investment. The rental rate of capital and the real wage decrease. This is due to the lower factor productivity induced by the fall in the public capital stock. Households demand a lower wage which reduces labor income for both household types and mutes consumption, in particular for credit-constrained households. Inflation and the interest

rate fall as marginal costs decrease due to the decrease in the rental rate of capital and the real wage.

After two years the highly negative consequences of the reduction in the public capital stock emerge. Output remains persistently below its initial level because the public capital stock deteriorates. Meanwhile, the decline in the debt-to-GDP ratio is very similar to the previous scenario. The fiscal rule in equation (31) accounts for the larger decline in output and government investment is reduced more than government consumption in the previous scenario to ensure a decreasing debt-to-GDP ratio. This large reduction in government investment amplifies the negative effects on output.

After about 5 years the decrease in government investment starts to reverse. After 10 more years government investment reaches the initial steady state level and rises even further. The long-run increase in productivity of hours and private capital are caused by the public capital stock and not directly by public investment. The dashed line in the graph on the lower right shows that the public capital stock continues to decrease even though public investment has already started to increase. The reason is that the level of public investment is still below the initial steady state level and therefore the depreciation of already installed public capital is larger than new public investment. Hence, the substantial long-run benefits of a final increase in public investment are not visible during the first 50 quarters. In line with this, output remains subdued for a long time. Roughly 30 years after the start of the consolidation output exceeds its initial steady state level for the first time.

4.3 Transmission of a transfer based consolidation

Figure 3 shows the impact of a transfer based consolidation strategy (*black lines*). The *grey lines* show for comparison the effects of a government consumption based consolidation. A transfer based consolidation strategy does not lead to such a strong decline in output as the other two expenditure based consolidations. The reason is that output is not directly affected by the transfer cuts, but only indirectly via the impact on private consumption and investment. The movements in output and most other variables are very small and mainly caused by the drop in consumption of the credit-constrained households. The transfer cut forces them to reduce consumption immediately. This reduction is also much more pronounced than in the aforementioned scenarios, where the reduction in consumption was solely due to lower wage income. By contrast, consumption of optimizing households barely moves at all. For them Ricardian equivalence applies. As the overall fall in production is much smaller than in the previous scenarios, hours worked and the capital utilization rate fall less. In turn, the rental rate of capital falls only little and wages increase only slightly. Further, the drop in inflation and the interest rate is much lower than in the previous scenarios. Thus, a consolidation via transfer payments has almost no effects on aggregate variables. Credit-constrained households are, however, highly affected and their consumption level drops considerably.

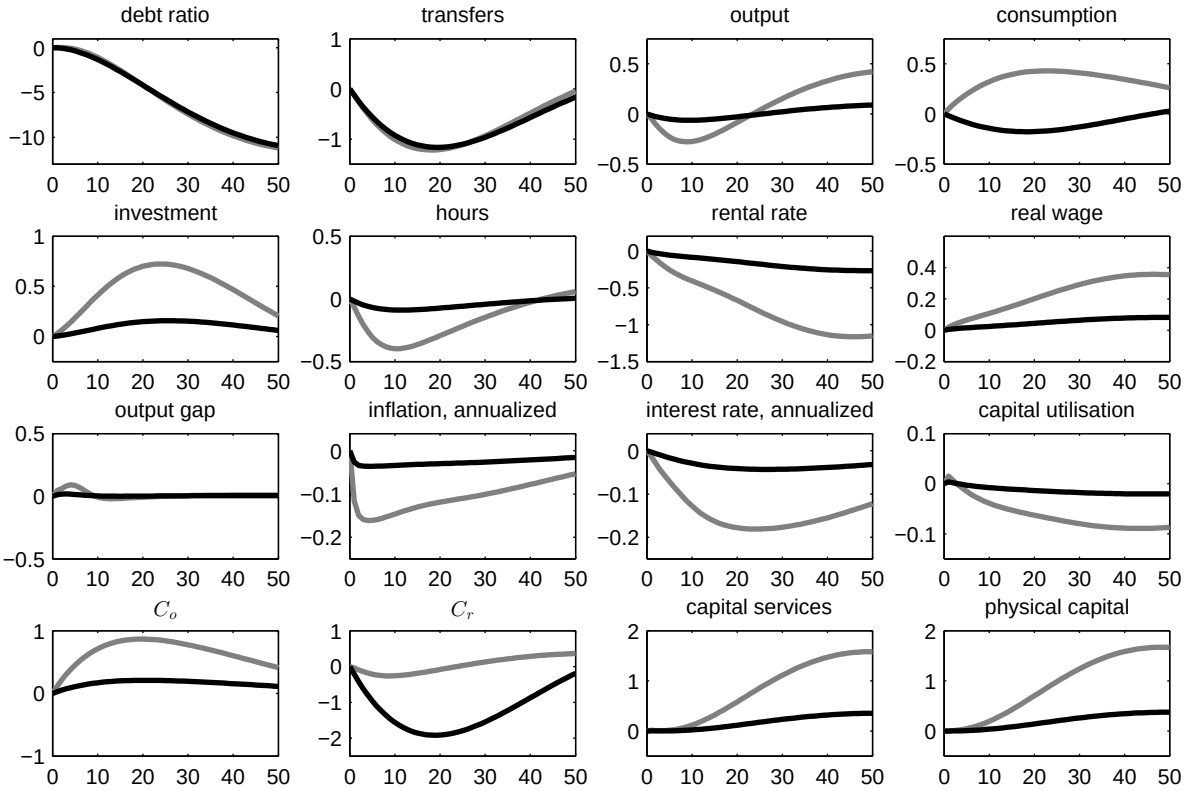

Figure 3: Transmission of consolidation via government transfers (*black lines*).
Notes: See figure 1. For comparison *grey lines* show the simulation results from figure 1 (consolidation via government consumption). Transfers are weighted with the initial output share.

4.4 Transmission of a consumption tax based consolidation

Figure 4 shows the effects of a consumption tax based consolidation (*black lines*) compared to a government consumption based consolidation *grey lines*. The short-run output costs are smaller than for a government consumption based consolidation. The main differences emerge with respect to consumption because the consumption tax has a direct effect on the price of the consumption good.

Optimizing households anticipate the gradual increase in the consumption tax rate and bring consumption forward to the first few quarters before it becomes more expensive. This leads to a small increase in consumption of optimizing households on impact. Thereafter, they start to reduce consumption smoothly. If there would be no gradual increase in the consumption tax rate then consumption would drop on impact. The reduction in consumption is more rapid for credit-constrained households. Firms respond to the lack in aggregate demand by employing less labor, which lowers income for all households. The reduction in income forces credit-constrained households to reduce consumption even further. While output falls less compared to the government consumption based consolidation, the increase in consumption tax revenues is muted by the declining consumption tax base. Thus, the path of the debt-to-GDP is very similar to the government consumption based consolidation.

Optimizing households use the cash-flow from the debt repayment of the government to invest in the physical capital stock in anticipation of the increase in long-run output. As the increase in the physical capital stock is not used in production for some time, the capital utilization

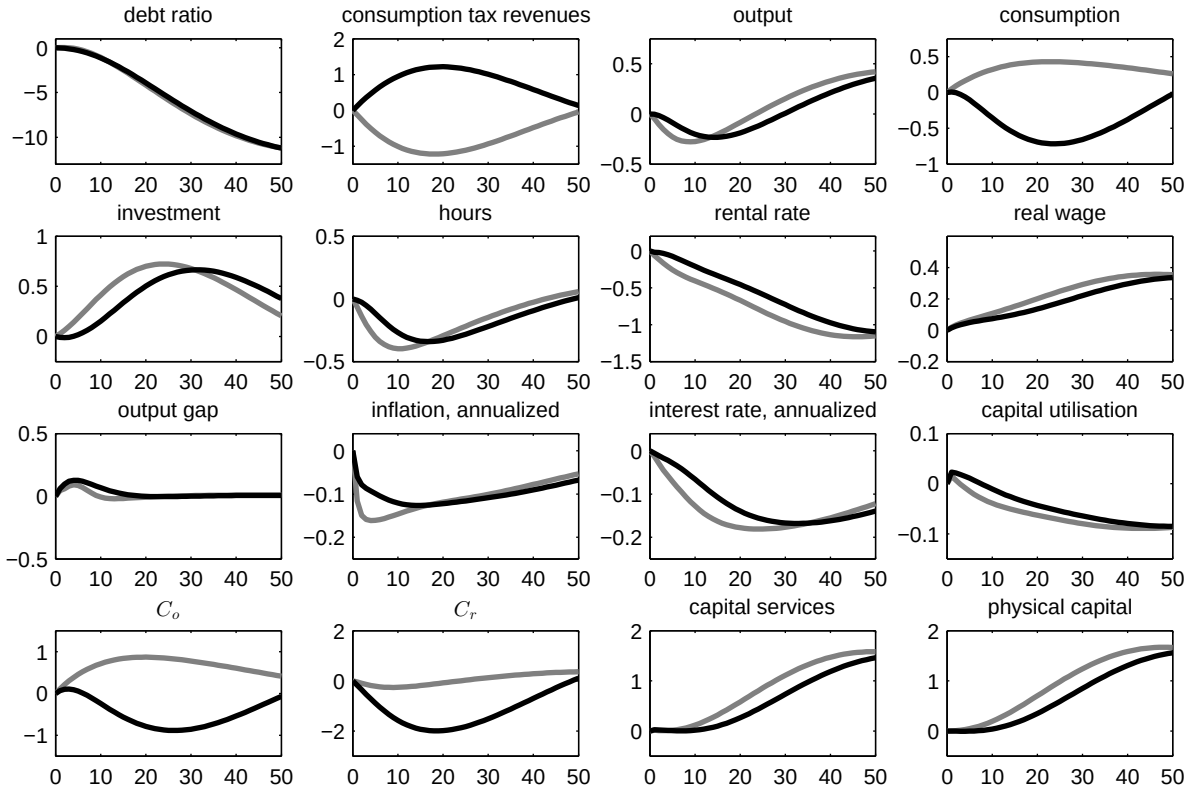

Figure 4: Transmission of consolidation via consumption taxes (*black lines*).
Notes: See figure 1. For comparison *grey lines* show the simulation results from figure 1 (consolidation via government consumption). Consumption tax revenues are weighted with their initial output share.

rate falls. The amount of capital services is roughly held constant during the first two years of consolidation. The tax hike increases the tax wedge between the marginal rate of substitution between labor and consumption and the real wage. As a consequence, optimizing households demand higher wages. The rental rate of capital decreases since the reduction in hours worked reduces the marginal product of capital services. Together, this implies a decrease in marginal costs. However, compared to the government consumption based consolidation the response is less volatile. Accordingly, the movements of inflation and the interest rate are muted as well. The movements of the output gap are again very small.

Output starts to increase once the increases in the consumption tax rate are reversed. Optimizing households increase consumption because the tax rate starts falling. However, this increase is relatively slow, because households anticipate that the tax rate will be cut further. This makes consumption today relatively more expensive compared to consumption tomorrow. Therefore consumption is postponed to some extent. Credit-constrained households cannot smooth consumption and increase their consumption directly once the consumption tax rate starts to decrease.

4.5 Transmission of a labor tax based consolidation

Figure 5 shows the transmission of a labor tax based consolidation (*black lines*). The contraction of output is much stronger and also much more persistent than for the case of a consolidation via government consumption (*grey lines*). The temporary tax increase does not only lead to a

fall in after-tax income, but also increases tax distortions on the labor market. Thus, incentives to work are reduced. The reduction in output is very persistent, because households postpone the final increase in hours worked until the reduction of the labor tax rate is reversed and the tax rate starts to decrease.

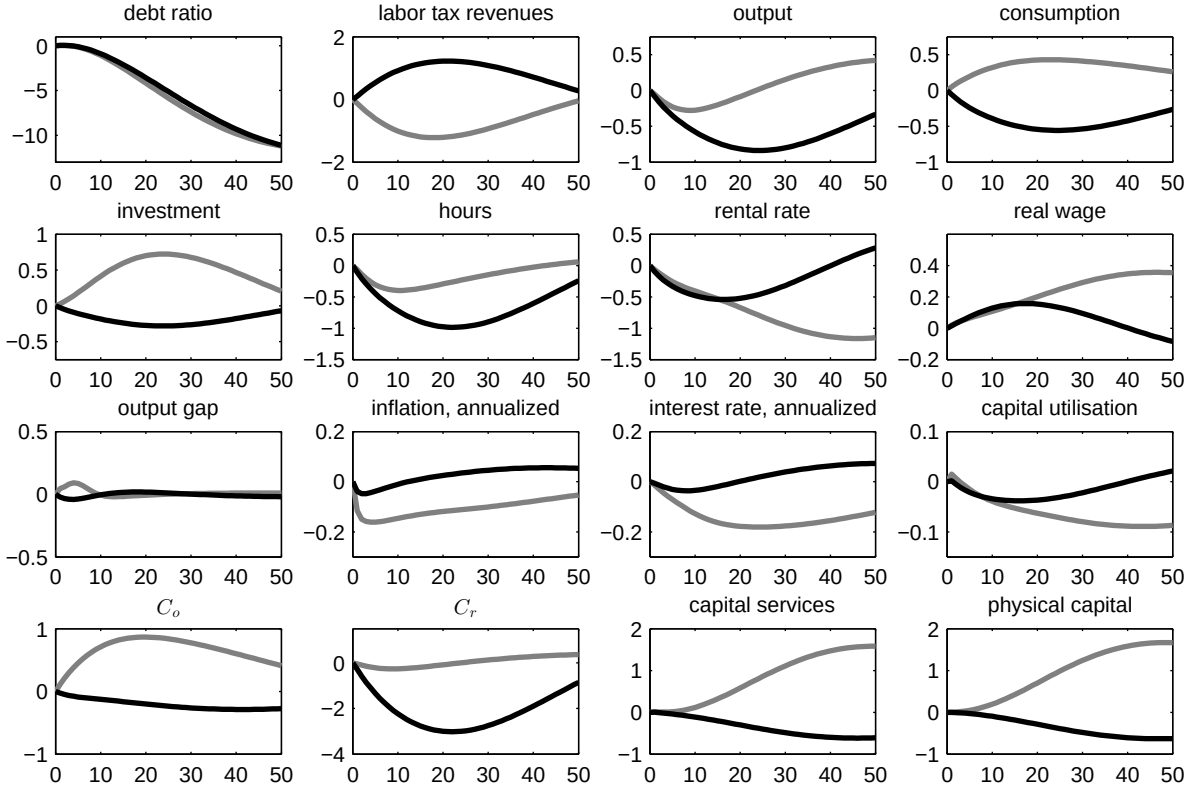

Figure 5: Transmission of consolidation via labor taxes (*black lines*).
Notes: See figure 1. For comparison *grey lines* show the simulation results from figure 1 (consolidation via government consumption). Labor tax revenues are weighted with their initial output share.

Households' labor income decreases because of the higher labor tax rate and the reduction in hours worked. Hence, they reduce consumption. In addition, the negative output effects are aggravated by a negative investment response. Optimizing households are able to smooth out the reduction in consumption over time so that the short-run decline is rather small. Credit-constrained households, however, need to adjust their consumption immediately. As less output is produced, investment and capital utilization fall. Effective capital used in production is reduced. The increase in labor taxes triggers a temporary rise in the real wage because households want to be partly compensated for the implied reduction in the after-tax real wage. The drop in hours worked reduces the marginal productivity of capital, so that the rental rate of capital falls. The overall effect on marginal costs is small so that inflation and the interest rate barely move at all.

The negative effects on output are highly persistent, so that investment is below its initial level for the first 50 quarters despite the anticipated increase in output in the final steady state. Output starts to exceed its initial level around 60 quarters after the beginning of the consolidation.

4.6 Transmission of a capital tax based consolidation

Figure 6 shows the effects of a capital tax based consolidation (*black lines*) compared to a government consumption based consolidation (*grey lines*). A capital tax based consolidation strategy has the strongest short-run impact on economic activity of all consolidation scenarios considered. Output declines by almost one percent during the first two years. The capital tax rate needs to be increased considerably from 36 percent to a peak value of 52 percent for the consolidation. The reason is that the initial tax base is relatively small compared to the labor and consumption tax scenarios because capital depreciation is exempted from taxation. The negative effects on GDP are very large so that the debt-to-GDP ratio even increases slightly on impact. Only after some quarters the debt-to-GDP ratio starts to fall as the deterioration of the tax base slows down. The decrease in output is caused by the fall in investment. An even quicker decrease of investment is prevented by investment adjustment costs.

Firms react to the decline in aggregate demand by reducing labor input and lowering production. On the contrary, the amount of capital services does not fall on impact. The reason is that we also observe a jump in the capital utilization rate. This jump is due to agents' anticipation of the change in the steady state rental rate for capital, induced by the lower steady state tax rate. As a consequence due to the reduction in hours, the rental rate on capital drops slightly on impact. The drop of the rental rate is reversed after 10 quarters, because of the strong reduction in the capital stock which ceteris paribus increases the marginal product of capital.

In the beginning of the consolidation phase aggregate consumption expands. This is solely due to the behavior optimizing households. They increase their consumption spending strongly because the increase in the capital tax rate lowers the value of installed physical capital. As a consequence, it is optimal for them to reduce investment spending strongly and use these funds instead for consumption. Wages fall somewhat due to the decrease in the marginal rate of substitution between labor and consumption. The drop in hours worked and wages leads credit-constrained households to reduce consumption immediately.

The output gap becomes negative. Inflation and the interest rate fall in the short run more than in the other scenarios because of the joint decrease in the rental rate of capital and wages that lead to a more pronounced decrease in marginal costs than in the previous scenarios.

Over time, the drop in the real wage and the rise in the rental rate lead firms to shift to a more labor intensive production. In addition, output is persistently below its initial level due to the strong reduction in the private capital stock. The capital stock starts to increase after 30 quarters, but it takes another 30 quarters until the initial steady state capital stock is reached again and the expansion starts to accelerate. Therefore, convergence to the final steady state is very slow.

4.7 Comparison of short-run transmission mechanisms

The above analysis shows that the transmission of fiscal policy and the size of the short-run output costs depend crucially on whether production factors are directly affected. The costs are particularly high for a consolidation via government investment or taxes on labor and capital. A cut in government investment reduces productivity of labor and private capital. A labor

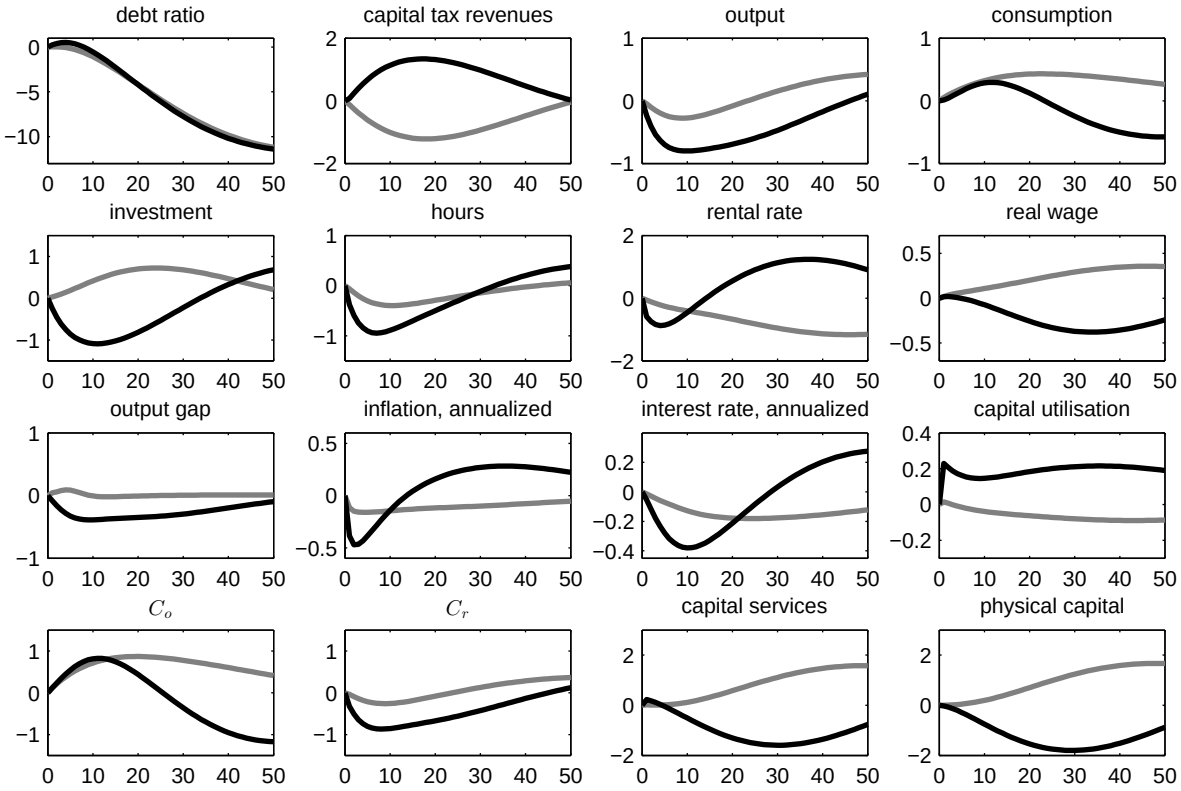

Figure 6: Transmission of consolidation via capital taxes (*black lines*).
Notes: See figure 1. For comparison *grey lines* show the simulation results from figure 1 (consolidation via government consumption). Capital tax revenues are weighted with their initial output share.

or capital tax rate hike increase tax distortions and lead to reductions in labor and capital input in production. By contrast, a consumption tax hike does not affect production inputs directly so that hours worked and output fall less. A cut in government consumption reduces in the baseline calibration demand, production and in turn labor income and consumption without increasing distortions or affecting productivity. If government consumption provides utility then the effects depend on the substitutability of private and public consumption. A reduction of transfers has almost no effect on output, but only on the consumption of credit-constrained households. Their consumption response turns out to be important for short-run dynamics in all consolidation scenarios, while consumption of optimizing households is less volatile as they smooth consumption.

The negative effects of fiscal consolidation are amplified because larger adjustments of the specific fiscal instruments are necessary to achieve a reduction in the debt-to-GDP ratio despite the contraction of output. This can lead to very persistent decreases in output if the private or public capital stock decrease as it is the case for government investment and taxes on labor and capital. The private and public capital stock continue to decrease even when fiscal policy is being reversed as long as investment is below the initial steady state and hence below the depreciation rate. Therefore, in these cases the reduction in output is highly persistent, while for government consumption, transfers and the consumption tax rate output recovers much quicker. Finally, for government consumption and investment based consolidations the short-run output costs depend not only on the reactions of consumption and investment through changes in the

budget of households, but output costs increase as the reduction in demand by the government reduces GDP directly.

5 Fiscal consolidation at the zero lower bound on interest rates

In this section we analyze the effects of fiscal consolidation when the central bank is constrained by the ZLB on nominal interest rates. To do so, we simulate a large recession and repeat the fiscal consolidation simulations in this environment. This scenario should be helpful in understanding how the effects of fiscal consolidation change in an environment that resembles the post-crisis situation of low interest rates and weak demand that many countries face currently.

In the baseline case the drop in the interest rate was small. Nevertheless, if the ZLB becomes binding conventional expansionary monetary policy becomes infeasible. In this case a prevention of lower nominal interest rates leads to rising real interest rates if inflation drops. This reduces consumption and output putting further downward pressure on inflation increasing the real interest rate further. This makes larger adjustments in fiscal instruments necessary to achieve a decrease in the debt-to-GDP ratio. These movements can potentially be very strong so that the debt-to-GDP ratio might even increase for some time rather than decrease.

5.1 Initial conditions for the zero lower bound

To create a recessionary environment which makes the ZLB actually binding we assume that the economy is hit by two recessionary shocks. The first shock is a negative consumption demand shock and the second shock is a negative investment shock (see equations (1) and (5)). These shocks are calibrated so that the simulated recession together with fiscal consolidation leads to a binding ZLB for five quarters. This is called the 'consolidation + recessionary shocks' scenario.[5]

In addition, we run a simulation in which the economy is hit by the recessionary shocks only, but where no fiscal consolidation takes place. We call this the 'recessionary shocks' scenario. In this case, the government is stabilizing the debt-to-GDP ratio at the initial level of 70 percent. In general, during this simulation the duration of the ZLB becomes shorter and for two fiscal instruments the ZLB does not bind because the negative fiscal impulse is missing.

Finally, we subtract the trajectories of macroeconomic variables of the 'recessionary shocks' scenario from the 'consolidation + recessionary shocks' scenario to isolate the effects of fiscal consolidation from those caused by the recessionary shocks. Changes of the dynamics caused by the binding ZLB are preserved. Hence, these simulation results of fiscal consolidation with a binding ZLB can be compared directly to the results in the previous section without any constraint on the nominal interest rate.

Our recession setup is similar to the one used in Christiano et al. (2011) and Erceg and Lindé (2013) who also simulate a recession in order to achieve a binding ZLB. Christiano et al. (2011) simulate a shock to the discount rate and a financial friction shock, while Erceg and Lindé (2013) use the same consumption demand shock as in our model in equation (1) and in addition a labor

[5] We calibrate the relative shock sizes to roughly mimic stylized business cycle facts for the variability in output, consumption and investment. Consumption is about 3/4 as volatile as output and investment is about 3 times more volatile than output.

augmented technology shock. In these models and in our model the combination of two shocks yields a drop not only in consumption, but also in investment.

As an example figure 7 shows the recessionary environment for the case of consolidation via government consumption. The *black lines* show the effects of fiscal consolidation when the economy is simultaneously hit by the recessionary shocks. The *grey lines* show the effects of the recessionary shocks without fiscal consolidation.

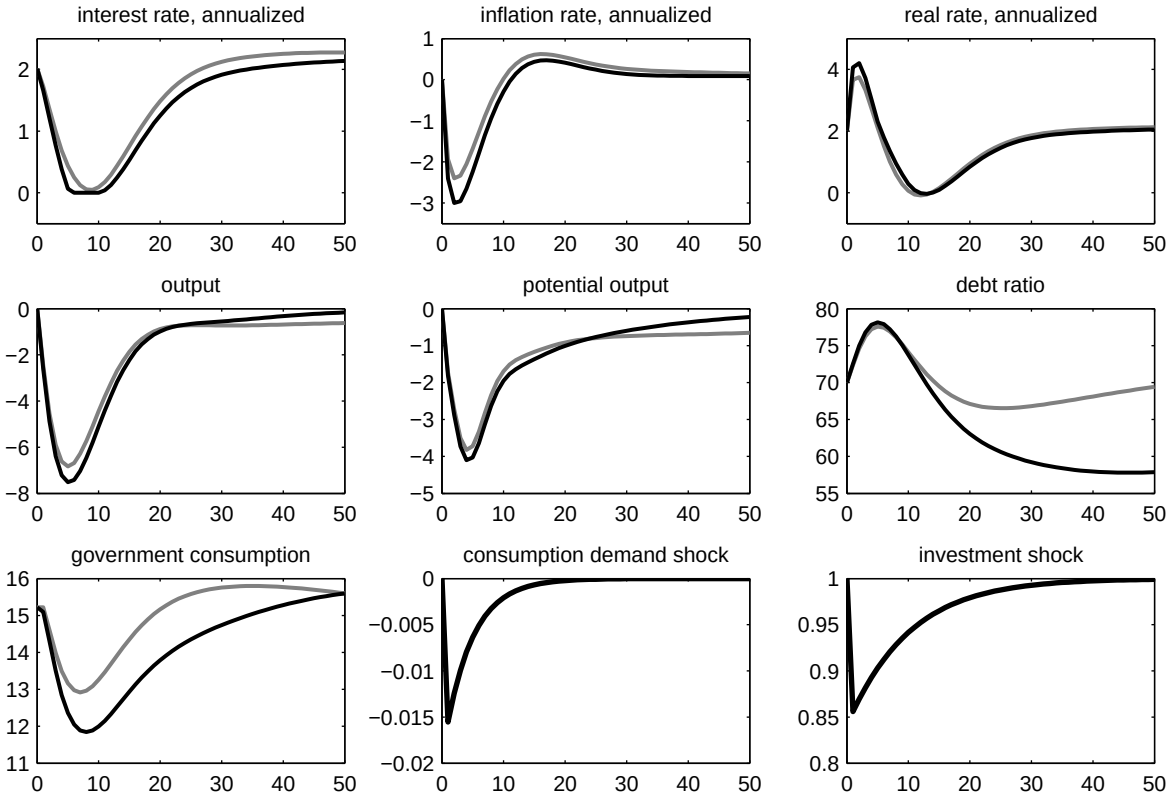

Figure 7: The recessionary environment.
Notes: Consolidation via government consumption. *Black line*: 'consolidation + recessionary shocks', *grey line*: 'recessionary shocks'.

In the 'consolidation + recessionary shocks' scenario the interest rate hits the ZLB for five quarters starting in the sixth quarter. We also observe a pronounced decrease in inflation which implies a strong increase in the real interest rate. Output declines strongly by around seven percent. This implies a deterioration in public finances which is reflected by an increase in the debt-to-GDP ratio by roughly eight percentage points.

For the other five consolidation scenarios we need larger recessionary shocks to achieve a binding ZLB of five quarters. In consequence, the recessionary environment differs across fiscal instruments in terms of the deepness of the recession. Table 3 gives an overview of the relative size of the recessionary shocks. The shocks for the consolidation via government consumption as shown in figure 7 are normalized to unity. The largest shocks occur in the case of a consolidation via labor taxes, which is almost twice as large as for a government consumption based consolidation strategy.

Once we isolate the effects of fiscal consolidation from the effects of recessionary shocks

by calculating the difference of the 'consolidation + recessionary shocks' and the 'recessionary shocks' scenarios, the influence of the difference in the shock sizes is neglectable.[6]

Table 3: Different shock sizes

	C_G	I_G	TR	τ^c	τ^n	τ^k
shock size	1	1.35	1.35	1.18	1.89	1.22

5.2 The effects of consolidation

Government consumption Figure 8 shows the simulation results for a government consumption based consolidation. The solid lines refer to the results of consolidation at the ZLB, whereas the dashed lines refer to the results for the baseline simulations without ZLB constraint. The drop in output is clearly amplified when the central bank is constrained by the ZLB. It is about three times larger compared to the simulation without ZLB constraint. The main reason for this is the pronounced drop of inflation on impact which leads to a sharp rise of the real interest rate compared to the baseline. In the beginning of the consolidation the central bank tries to counteract the drop in inflation by reducing the interest rate quickly, but in period six when the interest rate actually hits the ZLB the central bank is not able to accommodate anymore.[7,8]

Another reason for the amplification in the decrease in output is the reinforcing mechanism between output and government consumption via the fiscal rule. A stronger decrease in output leads to a stronger decrease in government consumption. This is necessary to achieve a falling debt-to-GDP ratio despite the large decrease in output. In the first few quarters, the decrease in government consumption even leads to a slight increase in the debt-to-GDP ratio before it finally starts to fall. The larger drop in output mainly affects credit-constrained households. They reduce consumption because of the reduction in wage income, while optimizing households smooth consumption so that the differences to the baseline scenario without ZLB are small.

The ZLB binds until period eleven. Afterwards, because of the large drop in output and inflation monetary policy is more expansionary than in the baseline scenario without ZLB. This monetary-fiscal policy interaction results in output converging back to the baseline within the next eight periods.

[6] In a linear model the differences in shock size would have no effect at all, once we net out the effects of the recessionary shocks. Here, we work with the non-linear model, so that a small effect of different shock sizes remains.

[7] The fact that the interest rate rises when the central bank is constrained by the ZLB might look counter-intuitive at first sight. The responses in figure 8 show, however, just the difference between the two scenarios shown in figure 7. There, the interest rate decreases faster in the 'consolidation + recessionary shocks' than in the 'recessionary shocks' scenario. So, figure 8 shows the part of the interest rate decrease that is caused by the consolidation and not the recession. In period six the interest rate hits the ZLB so that the difference between the 'consolidation + recessionary shocks' and the 'recessionary shocks' scenario shrinks which shows up as an increase in the interest rate in figure 8 once we subtract the 'recessionary shocks' scenario from the 'consolidation + recessionary shocks' scenario. After the ZLB does not bind anymore, the interest rate remains lower in the 'consolidation + recessionary shocks' scenario compared to the 'recessionary shocks' so that figure 8 shows a further expansion in monetary policy.

[8] In principle, a comparison between the ZLB and the no-ZLB scenario where the fiscal consolidation starts when the ZLB binds and not before would also be possible. In this case we would need, however, to construct a recessionary scenario that leads to a binding ZLB without fiscal consolidation. If we do this, on the one hand the period of a binding ZLB is different for different fiscal instruments so that the scenarios are not directly comparable anymore and on the other hand the simulations become infeasible for some instruments as the period of a binding ZLB becomes so long that there is no feasible equilibrium path for the economy.

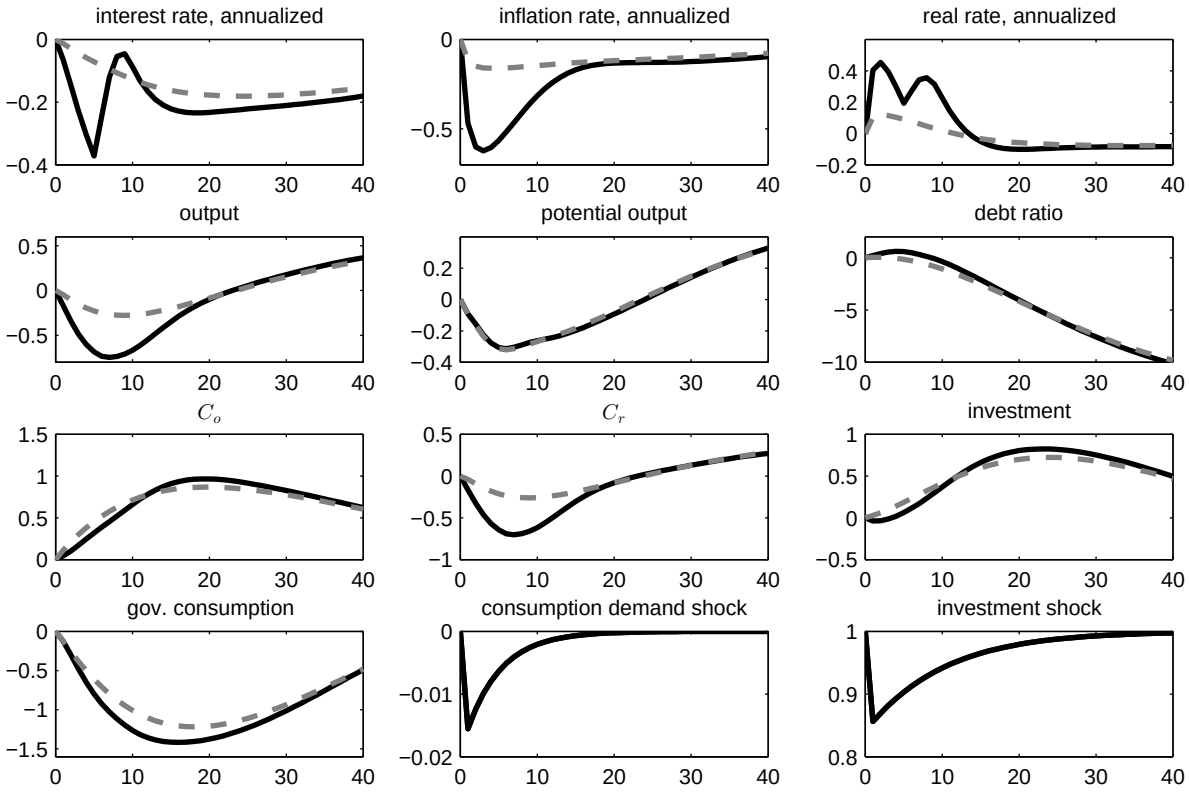

Figure 8: Transmission of consolidation via government consumption at the ZLB.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline.

Government investment Figure 9 shows the simulation results for the government investment based consolidation scenario. The negative effect on output is even much more amplified than in the government consumption based consolidation. As before, the decline in output in the beginning is to a large extend driven by the drop in inflation and the associated increase in the real interest rate. This effect fades out quickly when the ZLB is not binding anymore and the real interest rate returns to its baseline value. We observe, however, that output stays persistently below the path from the baseline scenario even after the real rate is back at the baseline. The persistently lower level of output is due to a stronger reduction in government investment because of the increase in the debt-to GDP ratio. This reduction in government investment has much more persistent effects than reductions in government consumption because the public capital stock shrinks. It takes longer to rebuild it, so that productivity of private production factors is persistently reduced even though the ZLB does not bind anymore. The larger reduction in output leads to a larger reduction of the consumption of credit-constrained households, while optimizing households are much less affected.

Transfers Figure 10 shows the case of a transfer cut based consolidation scenario. As with the two other expenditure instruments the amplification effect on output through the ZLB is very strong. The drop in GDP is about three times larger than in the baseline simulations. The overall magnitude of the reduction in output does not exceed 0.2 percent which is still low compared to the other instruments. The debt-to-GDP ratio is hardly affected so that the reduction in transfers is very similar to the baseline scenario. Further, the amplification of

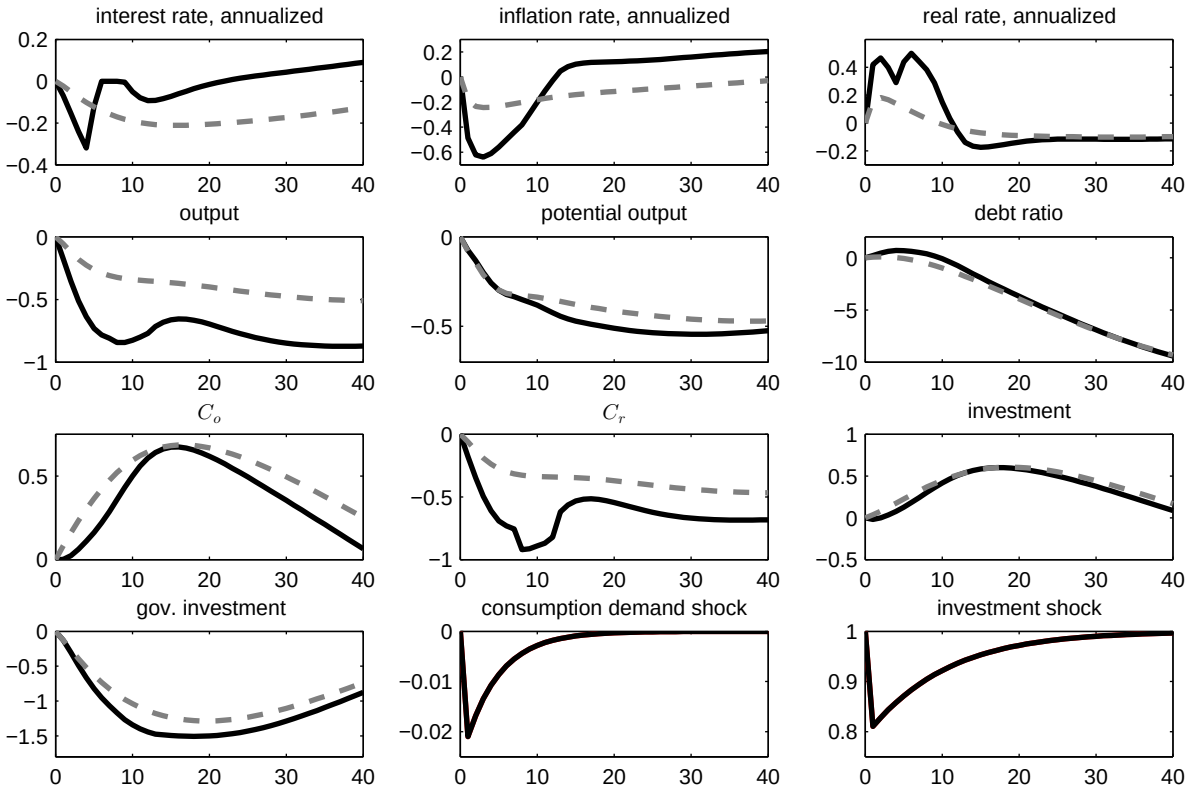

Figure 9: Transmission of consolidation via government investment at the ZLB.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline.

the negative implications for consumption of credit-constrained and optimizing households is small. In contrast to the government investment scenario the economy returns back to baseline relatively quickly when the ZLB is not binding anymore.

Consumption tax Figure 11 shows the case of a fiscal consolidation via the consumption tax rate. The drop in output is again amplified by the ZLB. The amplification is, however, lower compared to the expenditure scenarios. There, the drop in output was at least three times larger than in the scenario without ZLB, while here, the drop in output only doubles. As in the transfer based consolidation at the ZLB, consumption of both household types is affected to a similar extent. The transmission of the amplification works again through the drop in inflation which raises the real interest rate above baseline for at least ten quarters. The reduction in the debt-to-GDP ratio is delayed slightly by the ZLB. Therefore, the government increases the tax rate more than in the baseline case.

Labor tax Figure 12 shows the effects of consolidation via the labor tax rate. A striking feature of this consolidation scenario is that the drop in output is only little affected by the ZLB. At the trough of the output decline the output response is amplified by a factor of only 1.1. This is very much in line with Erceg and Lindé (2013), who find an amplification of the output response between $1.1 - 1.15$ when the labor tax rate is used to consolidate. Their analysis is based on a complex two country currency union model and they attribute the favorable outcomes in the labor tax case to open economy channels. We show that the small amplification of the output response also holds in a closed economy setup. In our model the main driving force is the

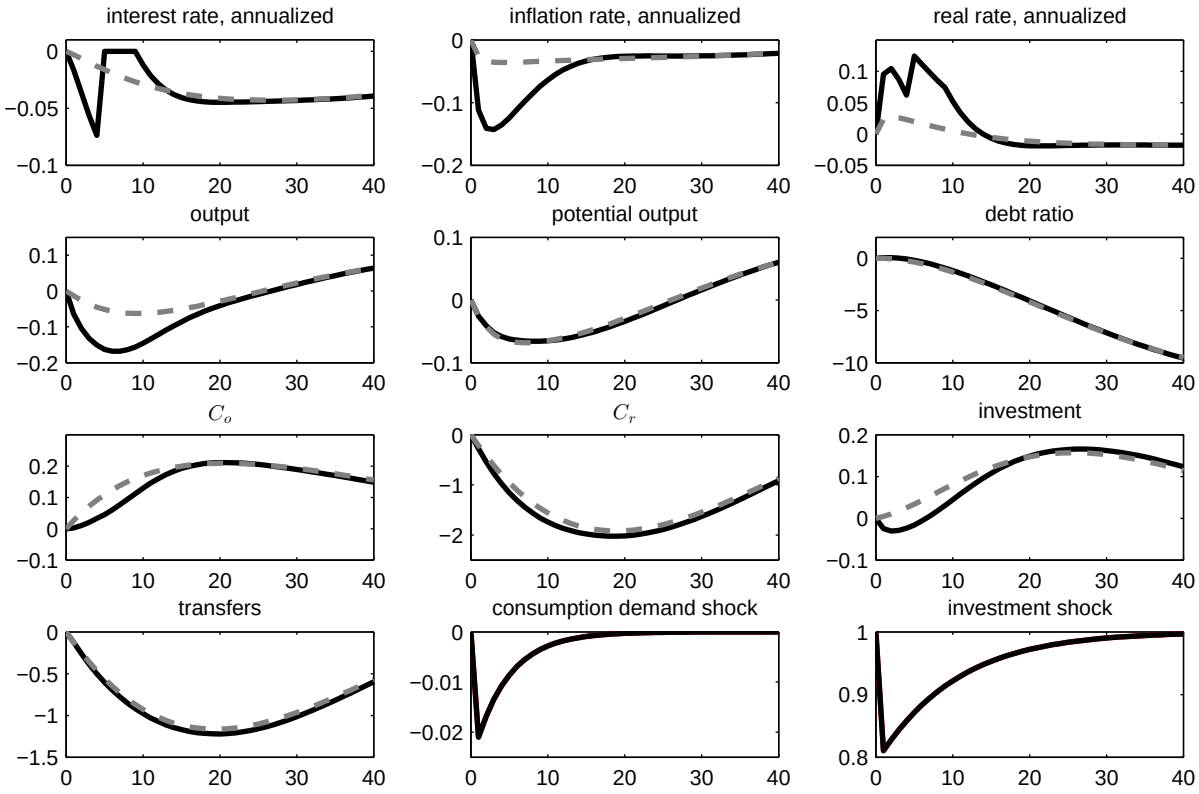

Figure 10: Transmission of consolidation via transfers at the ZLB.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline.

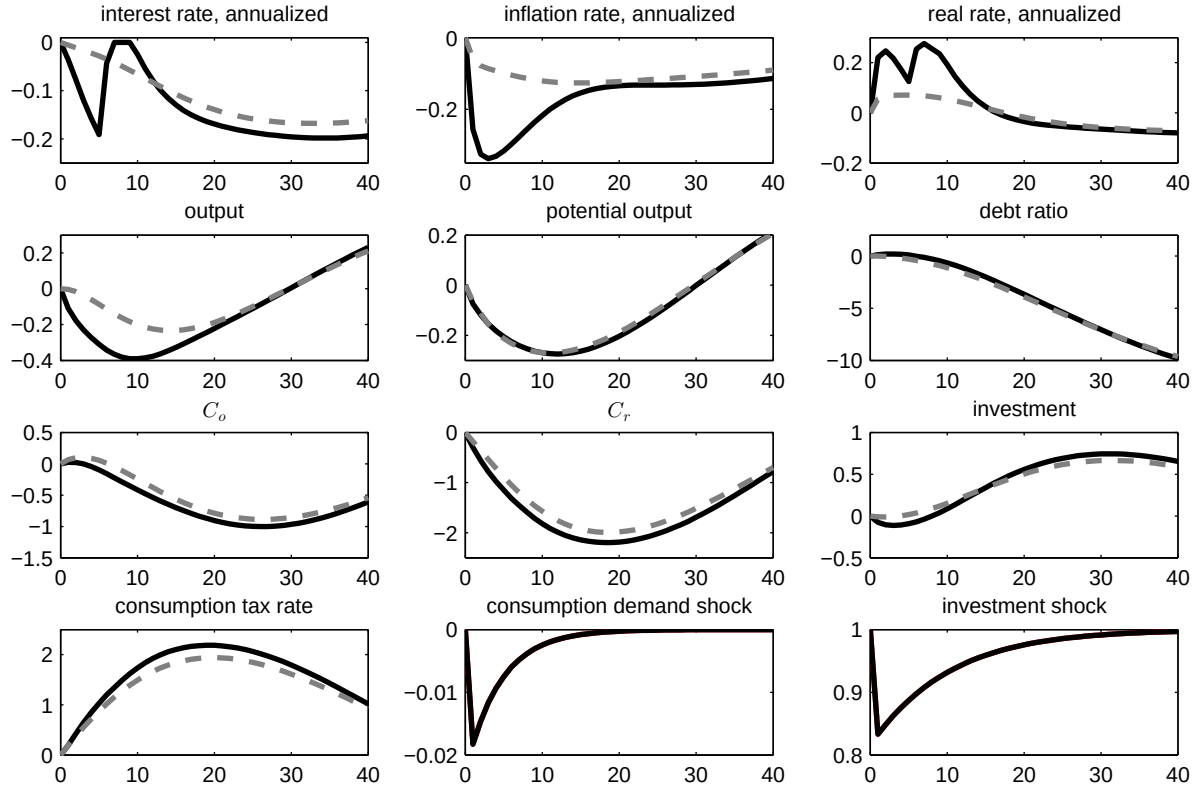

Figure 11: Transmission of consolidation via the consumption tax at the ZLB.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline.

marginal cost channel. As described in section 4 a consolidation via labor taxes leads in the short run to an increase in the real wage. This effect is now amplified at the ZLB as output decreases somewhat more which makes a somewhat larger increase in the labor tax rate necessary. Hence, households demand a higher wage compensation for the reduced after-tax wage. Figure 13 shows that this leads to an earlier increase in marginal costs compared to baseline. In turn, inflation expectations increase. Together, this prevents the inflation rate to drop on impact and therefore lowers the real interest rate instead of raising it.

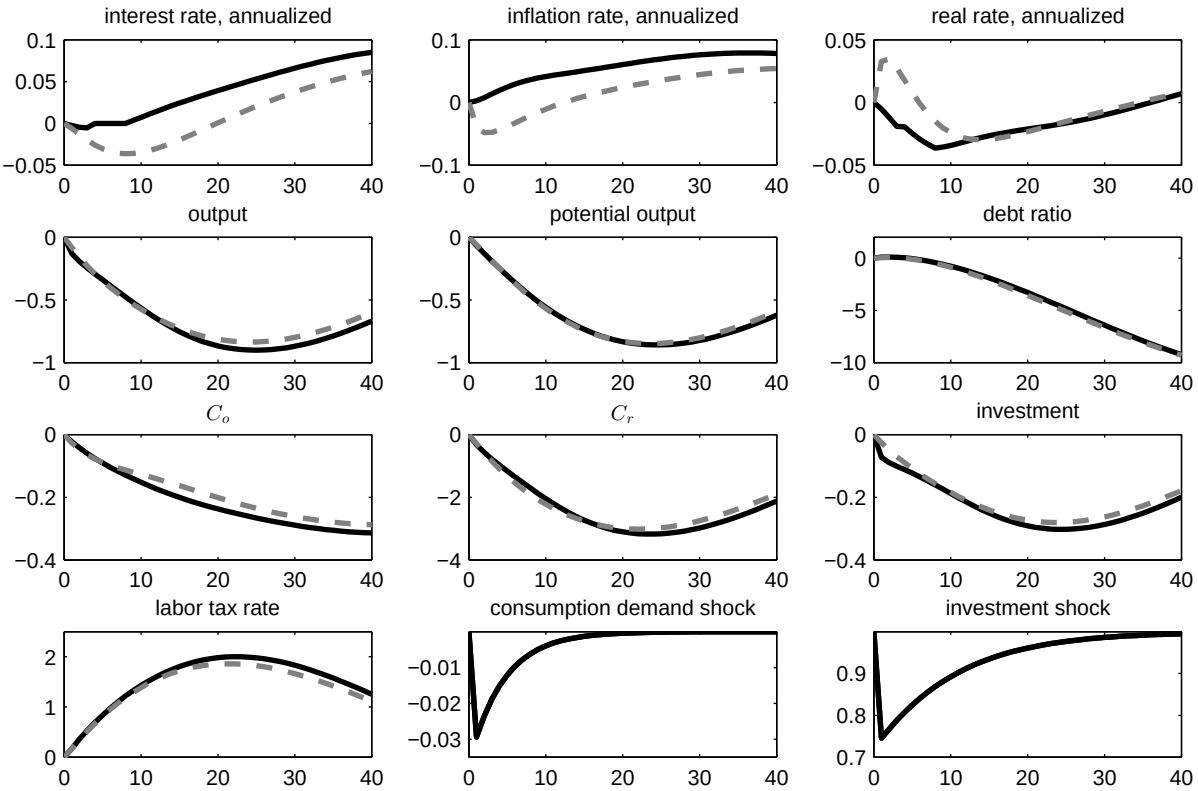

Figure 12: Transmission of consolidation via the labor tax at the ZLB.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline.

A lower real interest rate stimulates the economy and prevents output from dropping significantly below baseline.[9] Note, that in the analysis without ZLB the drop in inflation is also the lowest of all six consolidation scenarios. In addition, the drop in potential output is very strong so that only a small decrease in the interest rate is sufficient to keep output close to potential. Hence, the restriction on monetary policy caused by the ZLB is very small in this case.

Capital tax Finally, figure 14 shows the simulation results for the capital tax based consolidation. As in the other two tax based consolidation scenarios, the ZLB amplifies the negative output effects much less than in the expenditure based consolidation scenarios. As in all other

[9]Eggertsson (2010) finds that a labor tax cut at the ZLB actually deepens a recession because it puts downward pressure on inflation and leads to an increase in the real interest rate. Our scenario is exactly the opposite as we simulate a labor tax hike. We also find that this leads to an increase in inflation and a decrease in the real interest rate. However, in our case this does not have a stimulative effect on output. Our model is quite different, which might explain this difference. We study permanent rather than temporary policy changes, our model includes government debt, we have credit-constrained households, sticky wages and the labor tax rate adjusts endogenously to government debt.

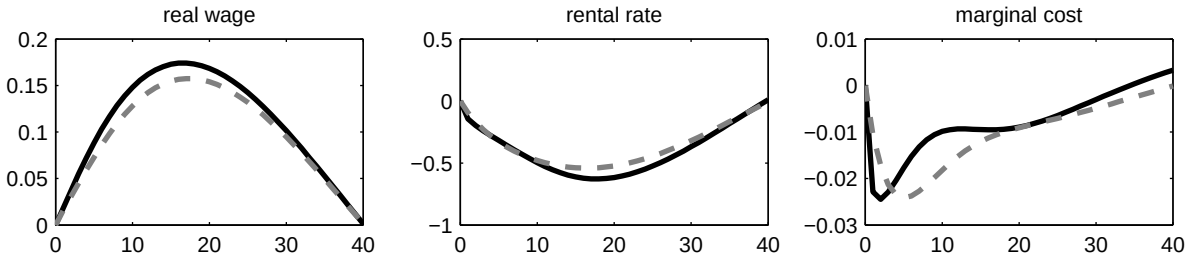

Figure 13: Marginal cost channel.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline. Variables are plotted as percentage changes.

cases the amplification works through the increase in the real interest rate and the stronger increase in the tax rate. At the ZLB the capital tax rate rises 19 percentage points above the initial level, whereas in the baseline the tax rate rises only 16 percentage points above the initial level. The moderate amplification does, however, not mean that a capital tax based consolidation is advisable. One should keep in mind that without the ZLB constraint the short-run negative effects are among the worst of all consolidation scenarios. They are even worse without ZLB constraint than some consolidation scenarios via other instruments with ZLB constraint. In addition this scenario has large distributional consequences. The fall in the consumption of credit-constrained households is much more amplified than the fall in the consumption of optimizing households.

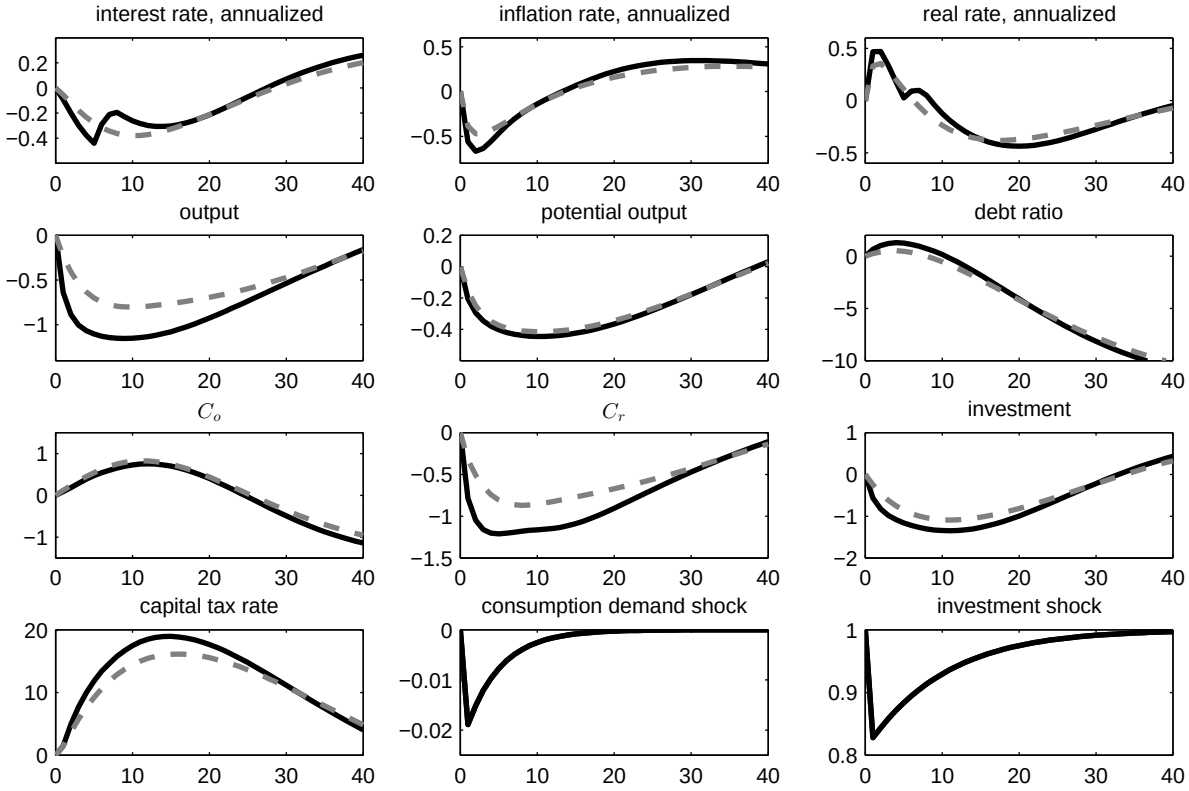

Figure 14: Transmission of consolidation via the capital tax at the ZLB.
Notes: *solid line*: effect of consolidation at ZLB, *dashed line*: baseline.

Summary The analysis showed that a binding ZLB amplifies the negative output effects by increasing the real interest rate. The effect is much stronger for expenditure based consolidations than for revenue based consolidations. The labor tax based consolidation is different from all other scenarios because the ZLB actually amplifies the increase in the real wage, which leads to an increase rather than a decrease in inflation. The real interest rate falls.

When deciding about the choice of the consolidation instrument not the amplification at the ZLB is important, but the size of the overall effect on output and other variables. Here, the results are similar to the analysis without ZLB constraint. The costs of an increase in transfers are the lowest despite the large amplification at the ZLB. The reason is that changes in transfers without ZLB constraint were extremely small. The second least negative effect on output is caused by the consumption tax rate. Without binding ZLB changes in government consumption had a similar effect on output as changes in the consumption tax rate. This changes because the negative effects of government consumption are amplified much more through the binding ZLB than the ones of the consumption tax rate. These three instruments have in common that the negative effects on output are not very persistent. The other three instruments (government investment, labor tax rate, capital tax rate) lead with and without ZLB to a reduction of the private or public capital stock and hence a persistent and deep output contraction.

6 Welfare effects of fiscal consolidation

While the policy debate and recent papers on fiscal stimulus and fiscal consolidation have focused on output developments, from an economic perspective welfare effects also matter. These can potentially be very different from output effects. To which extent a policy that leads for example to an increase in output also increases welfare depends on the paths of consumption and leisure. If the output increase leads to a large increase in hours worked, but only a modest increase in consumption, welfare might even decrease. In this section we compute welfare effects and compare them to the output effects of fiscal consolidation.

6.1 Calculating welfare measures

Welfare for optimizing households $V_{o,t}$ and for credit-constrained households $V_{r,t}$ is given by their lifetime utility functions. Aggregate welfare V_t is the sum of both weighted with their respective population shares:

$$V_{o,t} = \sum_{s=0}^{\infty} \beta^s \left(ln(\tilde{C}_{o,t+s} - h\tilde{C}_{o,t+s-1}) - \chi \frac{N_{o,t+s}^{1+\eta}}{1+\eta} \right) \tag{37}$$

$$V_{r,t} = \sum_{s=0}^{\infty} \beta^s \left(ln(\tilde{C}_{r,t+s} - h\tilde{C}_{r,t+s-1}) - \chi \frac{N_{r,t+s}^{1+\eta}}{1+\eta} \right) \tag{38}$$

$$V_t = (1-\zeta)V_{o,t} + \zeta V_{r,t}. \tag{39}$$

By evaluating equations (37) to (39) for different paths of $\tilde{C}_{o,t}$, $\tilde{C}_{r,t}$, $N_{o,t}$ and $N_{r,t}$, we can compute the welfare impact of different fiscal consolidation strategies.

To compute the welfare impact of the whole fiscal consolidation path from period one until the indefinite future we rewrite equations (37) and (38) recursively:

$$V_{o,t} = ln(\tilde{C}_{o,t} - h\tilde{C}_{o,t-1}) - \chi\frac{N_{o,t}^{1+\eta}}{1+\eta} + \beta V_{o,t+1} \tag{40}$$

$$V_{r,t} = ln(\tilde{C}_{r,t} - h\tilde{C}_{r,t-1}) - \chi\frac{N_{r,t}^{1+\eta}}{1+\eta} + \beta V_{r,t+1}. \tag{41}$$

Evaluating these expressions in $t = 1$ yields the welfare based on the paths of consumption and hours worked for all periods $t = 1, ..., \infty$ for the two household types owing to the perfect foresight assumption. We denote this by $V_{o,1}$ and $V_{r,1}$, respectively. Aggregate welfare is thus given by $V_1 = (1-\zeta)V_{o,1} + \zeta V_{r,1}$.

As these measures are difficult to interpret, we express the welfare effects in consumption equivalence units λ_o, λ_r and λ as in Schmitt-Grohé and Uribe (2006). Welfare effects expressed in consumption equivalence units can be interpreted as the permanent change in consumption that would be necessary to achieve the same change in welfare as through the impact of fiscal consolidation. These measures are implicitly given by:

$$V_{o,1} = \frac{1}{1-\beta}\left(ln((1-h)(1+\lambda_o)\tilde{C}_{o,i}) - \chi\frac{N_{o,i}^{1+\eta}}{1+\eta}\right) \tag{42}$$

$$V_{r,1} = \frac{1}{1-\beta}\left(ln((1-h)(1+\lambda_r)\tilde{C}_{r,i}) - \chi\frac{N_{r,i}^{1+\eta}}{1+\eta}\right) \tag{43}$$

$$\lambda = (1-\zeta)\lambda_o + \zeta\lambda_r, \tag{44}$$

where $\tilde{C}_{o,i}$, $\tilde{C}_{r,i}$, $N_{o,i}$ and $N_{r,i}$ denote initial steady state values for consumption and hours worked. The analytical solutions for λ_o, λ_r and λ are:

$$\lambda_o = \frac{\exp\left((1-\beta)V_{o,1} + \chi\frac{N_{o,i}^{1+\eta}}{1+\eta}\right)}{(1-h)C_{o,i}} - 1 \tag{45}$$

$$\lambda_r = \frac{\exp\left((1-\beta)V_{r,1} + \chi\frac{N_{r,i}^{1+\eta}}{1+\eta}\right)}{(1-h)C_{r,i}} - 1 \tag{46}$$

$$\lambda = (1-\zeta)\lambda_o + \zeta\lambda_r. \tag{47}$$

The simulation results in sections 3 and 4 showed that the implications of fiscal consolidation for consumption and leisure are very different in the short and the long run. Therefore, we also assess the welfare impact of the transition and the final steady state separately. To do so we first compute final steady state welfare, given by:

$$V_{o,ss} = \frac{1}{1-\beta}\left(ln((1-h)\tilde{C}_{o,f}) - \chi\frac{N_{o,f}^{1+\eta}}{1+\eta}\right), \tag{48}$$

$$V_{r,ss} = \frac{1}{1-\beta}\left(ln((1-h)\tilde{C}_{r,f}) - \chi\frac{N_{r,f}^{1+\eta}}{1+\eta}\right), \tag{49}$$

$$V_{ss} = (1-\zeta)V_{o,ss} + \zeta V_{r,ss}, \tag{50}$$

where $\tilde{C}_{o,f}$, $\tilde{C}_{r,f}$, $N_{o,f}$ and $N_{r,f}$ denote final steady state values for consumption and hours worked. By plugging in the final steady state welfare measures ($V_{o,ss}$ and $V_{r,ss}$) on the left hand side of equations (42) and (43) we can calculate the steady state change in welfare measured in consumption equivalents as in equations (45) to (47). We denote these changes as $\lambda_{o,ss}$, $\lambda_{r,ss}$ and λ_{ss}.

Finally, the welfare effects of the transition in consumption equivalence units can be computed by subtracting the steady state welfare effects from the overall welfare effects:

$$\lambda_{o,tr} = \lambda_o - \lambda_{o,ss}, \tag{51}$$

$$\lambda_{r,tr} = \lambda_r - \lambda_{r,ss}, \tag{52}$$

$$\lambda_{tr} = \lambda - \lambda_{ss}. \tag{53}$$

6.2 Welfare results

Table 4 shows the welfare effects of fiscal consolidation in consumption equivalence units.[10,11] The overall welfare effects amount to the equivalence of permanent changes in consumption between -0.13 percent and 0.01 percent. Per capita personal consumption expenditures in the US were 36289 dollar in 2013 so that the welfare changes in consumption equivalence units correspond to a range between -47 dollar ($-0.0013 * 36289$ \$) and +4 dollar ($0.0001 * 36289$ \$) per person per annum. Hence, the overall welfare effects are slightly negative except for fiscal consolidation via the labor tax rate. Looking at the welfare effects of the steady state and the transition shows, however, much larger values than the overall effects. While the steady state welfare effects are mostly negative, the welfare effects of the transition are mostly positive.[12]

The steady state welfare effects reflect the changes in consumption and hours worked in table 2. A long-run reduction of capital taxes has the most favorable effect. Welfare increases by the same amount that a permanent consumption increase of 0.1 percent would cause. On the one hand, this is due to the positive long-run effect on output, which leads to a substantial increase in consumption. On the other hand, the long-run reduction in the capital tax rate leads to a production structure that is more capital intensive. In consequence, hours worked increase only moderately, so that the associated welfare losses are small. All other consolidation strategies lead to lower overall welfare for the steady state comparison. The largest drop in welfare is associated with government consumption. In this case not only the increase in hours worked,

[10] Our measure of welfare is standard in quantitative business cycle models. It implies that an increase in hours worked reduces welfare and vice versa. In some models with involuntary unemployment labor market fluctuation are modelled only at the extensive margin. In this case the effect of hours worked on welfare is missing.

[11] The results are computed for the case without ZLB restriction on nominal interest rates. We do not analyse welfare effects under the ZLB because a binding ZLB even increases welfare slightly in five out of the six scenarios. This is caused by the larger reduction in hours worked, i.e. a larger increase in leisure, while the additional negative effects on consumption are less strong.

[12] The differences between transitional and steady state welfare effects can be interpreted as a rough indication of intergenerational distributional welfare consequences. As the convergence to the final steady state takes in several cases very long, the steady state effects concern future generations more than current generations, while the transitional welfare consequences impact only current generations.

Table 4: Welfare effects of fiscal consolidation

	C_G	I_G	TR	τ^c	τ^n	τ^k
λ	-0.13	-0.04	-0.01	-0.09	0.01	-0.04
λ_{ss}	-0.60	-0.10	-0.05	-0.26	-0.33	0.10
λ_{tr}	0.47	0.06	0.03	0.17	0.34	-0.15
λ_o	-0.16	-0.06	-0.02	-0.11	0.02	-0.10
$\lambda_{o,ss}$	-0.69	-0.20	-0.15	-0.35	-0.43	0.05
$\lambda_{o,tr}$	0.54	0.13	0.13	0.24	0.45	-0.16
λ_r	-0.04	0.02	0.00	0.00	-0.01	0.14
$\lambda_{r,ss}$	-0.32	0.17	0.27	0.03	-0.01	0.25
$\lambda_{r,tr}$	0.28	-0.15	-0.26	-0.03	0.00	-0.12
Welfare-based rank (ss)	6.	3.	2.	4.	5.	1.
Output-based rank (ss)	4./5.	1.	6.	4./5.	3.	2.

Notes: λ, λ_{ss} and λ_{tr} denote the overall, steady state and transitional welfare effects of a fiscal consolidation in consumption equivalence units. The subscripts o and r denote the respective measures for optimizing and credit-constrained households. Positive numbers imply an increase in welfare, while negative numbers imply a decrease in welfare. The last two rows rank the steady state effects of the different consolidation scenarios according to their welfare output effects.

but also the considerable crowding-out of private consumption leads to a large drop of welfare in consumption equivalence units of 0.6 percent which corresponds to -218 dollars per person per annum.[13] For the other fiscal instruments the reduction in welfare ranges from 0.05 percent for transfers to 0.33 percent for labor taxes. These fiscal instruments have in common that the long-run increase in consumption is not sufficient to compensate the drop in welfare associated with the increase in hours worked.

For the transition period the results change dramatically compared to the steady state welfare effects. The government consumption scenario leads to a 0.47 percent increase in welfare, whereas the capital tax scenario causes a 0.15 percent decrease. The main reason for large welfare difference for these two instruments is the short-run response of consumption. As shown in figure 6 the path of aggregate consumption for the capital tax base consolidation is below the path of consumption for the government consumption scenario. For the remaining four instruments the transitional welfare effects are positive owing to the temporary increase in leisure.

It is worthwhile to compare the welfare effects of the two household types. Based on overall welfare optimizers are negatively affected by most fiscal consolidation strategies, while the overall welfare impact on credit-constrained households is close to zero for most consolidation strategies. During the transition, however, credit-constrained households are mostly negatively affected, while optimizers' welfare increases. As one can easily see in figures 1 to 6, the reason for this is that optimizers are able to smooth their consumption path during the transition period, whereas credit-constrained households can only rely on their current labor income to finance consumption. With respect to steady state welfare credit-constrained households are better of than optimizing households. As both household types work the same amount of hours the reason for these differences must be routed in the consumption response. Table 2 shows that the percentage steady state increase in consumption is indeed larger for credit-constrained households than for optimizing households. This is because optimizing households also increase their investment spending to build up the capital stock needed for production. In this sense credit-constrained households benefit from the increase of output due to the higher capital stock, which is solely

[13]It is important to mention that for this simulation we assume that government consumption does not provide utility to households.

financed by the optimizing households.

6.3 Comparison of the output and welfare impact of fiscal consolidation

In the short run, it might be misleading for a policy maker to judge the effectiveness of a consolidation plan solely by taking overall output effects into account. For example, in section 4 we found that a transfer based consolidation barely reduces output during the transition to the final steady state. But with respect to welfare we find that credit-constrained households suffer substantial welfare losses (-0.26 percent), while optimizing households gain welfare (0.13 percent). These differences are rooted in the different consumption responses of households. In addition, this redistribution among the two household types is not visible when looking only at aggregate welfare. On the aggregate, the aforementioned welfare effects cancel out to a large extend so that welfare is slightly positive (0.03 percent) during the transition. We also found that a labor tax based consolidation leads to large and persistent output reduction during the first years of the consolidation. At the same time we observe that such a consolidation strategy involves substantial overall welfare gains during the transition to the final steady. This is because the drop in output is associated with a reduction in hours worked. In this case, output and welfare effects run into opposite directions. For a policy maker, these two examples highlight the need for a careful design of a consolidation plan because output and welfare effects might run into opposite directions and different household types might be affected very differently.

Similarly, the steady state welfare and output effects are very different. While the long-run output effects are positive for all fiscal instruments, the steady state welfare effects are negative except for the capital tax rate scenario. The last two rows of table 4 rank the different consolidation instruments based on long-run output and steady state welfare effects. A capital tax based consolidation leads to an increase in the capital intensity of production and therefore has favorable effects from a welfare and an output perspective. For most of the other instruments the long-run increase in hours and output is the same. So, a large increase in hours leads to a large increase in output, but also to large welfare costs.

Overall, the welfare and output based fiscal consolidation effects are quite different. We want to stress these crucial differences as the debate has so far mainly focused on output developments, but from an economic point of view welfare effects are at least as important.

6.4 Welfare effects with utility enhancing government consumption

Our previous analysis of output effects of fiscal consolidation via government consumption showed that it matters crucially for the results whether or not government consumption provides utility to households. Table 5 shows the welfare results for a consolidation via government consumption for the baseline case and if government consumption provides utility as a substitute or complement to private consumption.

The results show that if government consumption provides utility overall welfare is mainly determined by the steady state welfare effects, while the transition has almost no effect on welfare at all. Here, it is important to recall that the consumption bundle $\tilde{C}$ that consists of private and public consumption is the relevant variable for the evaluation of the consumption

Table 5: Welfare effects of utility enhancing government consumption

	baseline ($\kappa_c = 1$)	substitutes ($\kappa_c = 0.75$, $\nu = 1.5$)	complements ($\kappa_c = 0.75$, $\nu = 0.5$)
λ	-0.13	-0.05	-0.14
λ_{ss}	-0.60	-0.06	-0.17
λ_{tr}	0.47	0.02	0.03
λ_o	-0.16	-0.06	-0.19
$\lambda_{o,ss}$	-0.69	-0.14	-0.22
$\lambda_{o,tr}$	0.54	0.08	0.03
λ_r	-0.04	0.00	-0.01
$\lambda_{r,ss}$	-0.32	0.16	-0.01
$\lambda_{r,tr}$	0.28	-0.20	-0.02

Notes: See table 4.

impact on welfare if $\kappa_c < 1$. In the substitution case the transitional movements in consumption and hours worked are small as shown in figure 1. In the complement case the large transitory decrease in consumption is accompanied by a large transitory decrease in hours worked, i.e. an increase in leisure, so that these two effects cancel out each other in terms of the welfare impact. For the steady state welfare effects the long-run increase in government consumption leads to an increase of $\tilde{C}$ in the final steady state. This increase is much stronger if private and public consumption are complements compared to the case where they are substitutes. Hours worked also increase in the final steady state in both cases—though much less in the substitution case—, so that the overall welfare impact is still negative.

7 Conclusion

We have analysed fiscal consolidation in a dynamic general equilibrium model. Using one coherent framework makes the effects of different but connected aspects—including many fiscal instruments, the zero lower bound on interest rates and a welfare analysis—directly comparable. The results show that the choice of the consolidation instrument is very important. Instruments that lead to a reduction of either the private or the public capital stock lead to very pronounced and persistent output contractions, while the short-run output costs for other consolidation strategies are much smaller. While a binding zero lower bound on nominal interest rates increases short-run output costs in particular for expenditure based fiscal consolidation, the overall ranking of consolidation strategies in terms of short-run output costs does not change. We find that fiscal consolidation affects consumption of credit-constrained households more than of optimizing households for all six considered fiscal instruments. This leads to a negative welfare impact on credit-constrained households during the transition for most consolidation scenarios. In contrast, in the long run credit-constrained households benefit more from fiscal consolidation. Output increases due to the additional fiscal space caused by lower required interest rate payments by the government. Optimizing households need to use part of their additional income to invest in physical capital to support the increase in steady state output, while credit-constrained households can consume all additional income.

We analyse fiscal consolidation via one instrument at a time to clearly separate the effects of different instruments. For a practical fiscal consolidation plan policymakers can use the

analysis to come up with a consolidation plan that consists of a combination of different fiscal instruments. For example, a plan that would avoid a large short-run output contraction and lead to a substantial long-run increase in output, would consist of temporary cuts in government consumption, transfers or a temporary increase in the consumption tax rate and long-run cuts in the labor or capital tax rate and an increase in government investment. To avoid large negative distributional and welfare effects, such a plan should specifically include those categories of government consumption and transfers, that affect credit-constrained households less than fully optimizing households. To further mitigate short-run negative consequences, one can phase in capital tax cuts or increases in government investment early on and not only in the long run. Such a combined strategy might be particularly useful if fiscal consolidation needs to be done when the zero lower bound on nominal interest rate binds and short-run output costs are potentially large.

The analysis in our paper is conducted under perfect foresight. A perfectly credible policy plan can lead to an increase in consumption of optimizing households even in the short-run if a long-run income increase is anticipated. If a policy plan is not fully credible, then such positive effects might be smaller. Hence, in reality a clear commitment to a fiscal consolidation plan is important. Furthermore, in reality political economy aspects might influence the way a consolidation plan is set up. In particular, it might be difficult to reverse a temporary increase in tax rates. If this is the case and households anticipate that a final tax cut is unlikely, then the negative consequences in terms of output and welfare can increase. Thus, for practical applications such restrictions on the feasibility of a plan need to be taken into account.

For future work, the analysis of fiscal consolidation plans without perfect credibility or perfect foresight is of interest. Further, extending our analysis to additional instruments would be helpful. For example, government spending on eduction might increase human capital and enhance the long-term productivity of the workforce. In addition the inclusion of involuntary unemployment would be interesting for two reasons. First, it would be interesting to study how the welfare implications change if not all adjustments of labor are done along the intensive margin. Second, one could study changes in unemployment benefits which might affect the natural rate of unemployment and the long-run output level. Finally, while our model includes a constant share of credit-constrained households, in reality fiscal consolidation might change this share. Therefore, modeling fiscal consolidation with heterogenous agents and an endogenously changing share of credit-constrained households would be very interesting.

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