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Fiscal Stimulus in Liquidity Traps: Conventional or Unconventional Policies?

Matthieu Lemoine[1], Jesper Lindé[2]

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ABSTRACT

Recent influential work argue that a gradual increase in sales tax stimulates economic activity in a liquidity trap by boosting inflation expectations. Higher public infrastructure investment should also be more expansive in a liquidity trap than in normal times by raising the potential interest rate and increasing aggregate demand. We analyze the relative merits of these policies in New Keynesian models with and without endogenous private capital formation and heterogeneity when monetary policy does not respond by raising policy rates. Our key finding is that the effectiveness of sales tax hikes differs notably across various model specifications, whereas the benefits of higher public infrastructure investment are more robust in alternative model environments. We therefore conclude that fiscal policy should consider public investment opportunities and not merely rely on tax policies to stimulate growth during the COVID-19 crisis.[3]

Keywords: Monetary Policy, Sales Tax, Public Investment, Liquidity Trap, Zero Lower Bound Constraint, DSGE Model.

JEL classification: E52, E58

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[1] Banque de France, matthieu.lemoine@banque-france.fr

[2] IMF and CEPR, jlinde@imf.org

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NON-TECHNICAL SUMMARY

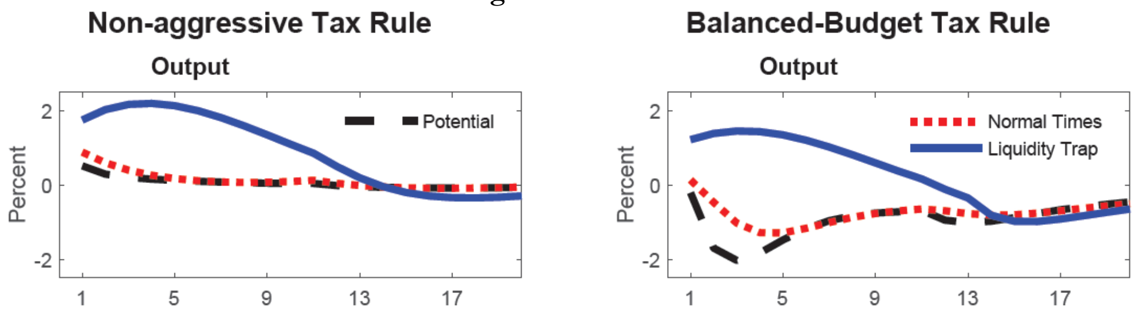
The recent academic literature has promoted a new type of tax-based unconventional policy which may stimulate growth while being self-financed: a credible commitment to a higher future sales tax would boost demand by increasing households' incentives to consume more today. Higher public infrastructure spending, a more conventional fiscal policy, has also received significant attention for two reasons. First, given the low level of public investment in leading economies, the marginal returns on certain types of higher spending are likely elevated. Second, higher public investment combines the benefits of providing higher demand when the economy is in a recession and raising potential output afterward.

Our starting point is that the gains of policies that are pursued in practice should be robust across different models. In this vein, we begin our analysis using a stylized New Keynesian model with a fixed private capital stock. Next, we move on to examining the robustness of the results in a more empirically-realistic model, a two-agent New Keynesian (TANK henceforth) model with endogenous formation of private capital and hand-to-mouth agents. In both models, we assume that the government uses either a non-aggressive fiscal rule based on the labor income tax rate, such that this tax rate remains almost constant after standard shocks at a five-year horizon, or a balanced-budget rule based on the same tax.

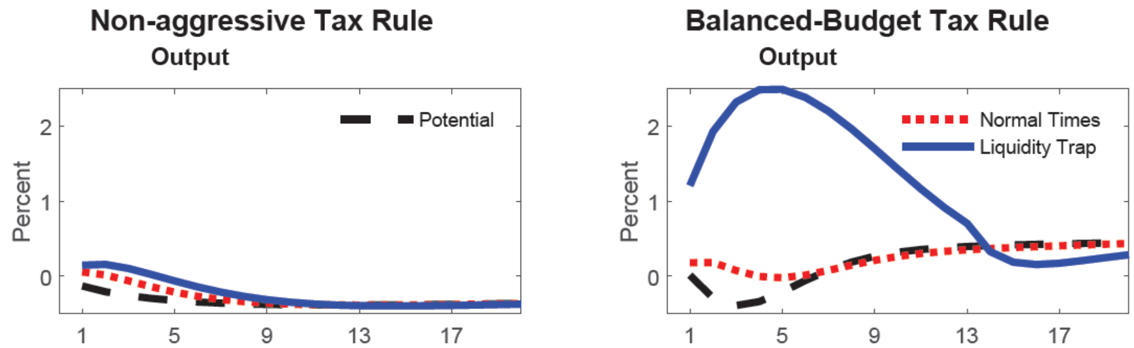
Our main findings are as follows. First, we find a lack of robustness of the unconventional fiscal policy in a long-lasting liquidity trap: a gradual tax hike strategy works well in the stylized model, but, within the TANK economy, such a policy strategy quicly becomes contractionary unless labor income taxes are cut aggressively to balance the surplus (figure below). Second, higher public infrastructure spending has robust favorable effects on output across both models. Our conclusion is that fiscal reforms should therefore consider public investment opportunities and not exclusively rely on tax policies to stimulate growth.

Figure. Conventional and Unconventional Policies in the TANK Model.

A. Higher Public Investment



B. Gradual Sales Tax Hike



Stimulus budgétaire dans des trappes à liquidité: politiques conventionnelles ou non conventionnelles?

RÉSUMÉ

De récents travaux influents défendent l'idée selon laquelle une hausse graduelle des taxes à la vente stimule l'activité économique dans une trappe à liquidité en nourrissant les anticipations d'inflation. Un niveau plus élevé d'investissement public devrait également être plus expansionniste au sein d'une trappe à liquidité qu'en temprs normal en remontant le taux d'intérêt potentiel et la demande agrégée. Nous analysons les mérites relatifs de ces politiques en utilisant des modèles nouveaux keynésiens comprenant ou non une formation endogène du capital privé et de l'hétérogénéité, lorsque la politique monétaire ne répond pas en relevant son taux directeur. Nous trouvons principalement que l'efficacité des hausses de taxe à la vente dépend substantiellement des spécifications retenues, alors que les gains obtenus en cas de hausse de l'investissement public en infrastructure sont plus robustes à ces différents types de modélisation. Nous en concluons donc que la politique budgétaire devrait considérer favorablement les opportunités d'investissement public et ne pas s'appuyer uniquement sur des politiques fondées sur la fiscalité pour stimuler la croissance en période de crise du COVID-19.

Mots-clés : politique monétaire, taxe à la vente, investissement public, trappe à liquidité, contrainte de borne inférieure à zéro, modèle DSGE.

1. Introduction

Keynes argued for aggressive fiscal expansion during the Great Depression on the grounds that the fiscal multiplier was likely to be much larger in a liquidity trap than in normal times, and the financing burden correspondingly smaller. In today's coronavirus crisis environment in which economic activity in many advanced and emerging markets economies is expected to remain subdued, rates of price and wage inflation are low or even absent, and equilibrium real rates are close to or even at record-low levels, there is again a strong case to be made for fiscal stimulus as monetary policy is constrained by its effective lower bound (see for example chapters 1 and 2 in IMF (2020) and the discussion in Gaspar et al., 2016) and may have limited scope to provide sufficient stimulus to the economy through unconventional policy tools.

In this unprecedented environment, there is a strong case for fiscal stimulus (see Gopinath, 2020, and Summers, 2020). However, the ability to provide unconstrained large-scale fiscal stimulus during this coronavirus crisis will be impeded by the elevated post-global financial crisis debt levels. Given the initial high debt levels, and the continued headwinds to public finances due to subdued projected growth rates and unfavorable future demographic developments, any sizeable fiscal stimulus must be nearly or completely self-financing.

In this context, the recent academic literature has promoted a new type of tax-based policy which may stimulate growth while being self-financed. In order to distinguish it from the *conventional fiscal policy* advocated by Keynes that is spending-based, this strategy has been referred to as *unconventional fiscal policy*. It builds on the important theoretical work by Correia et al. (2013) and a key ingredient in it is a gradually higher path of the sales tax. A credible commitment to a higher future sales tax boosts domestic demand by reducing the wedge between the actual and the potential real rate; it increases the equilibrium real rate and lowers the actual real rate through higher inflation and inflation expectations. According to the consumption Euler equation, this policy thus increases households' consumption today. Moreover, by boosting economic activity this strategy also increases tax revenues (through higher tax rates and expanding the tax bases), shrinks the public deficit and reduces government debt as a share of GDP. In order to make the policy budget neutral, the higher sales tax can be combined with lower labor income/pay-roll tax and provide further boost to economic activity. Such a "grand fiscal bargain" package has been referred to by Farhi et al. (2014) as a fiscal devaluation, as it mimics the effects of a currency depreciation under fairly general conditions. Empirically, D'Acunto et al. (2016, 2018) examine the effects of announced VAT hikes in Germany and Poland, finding evidence that they generate higher inflation expectations, lower real interest rates, and higher consumer spending. The German government recently implemented this type of policy to stimulate growth during the coronavirus crisis.[1]

Another conventional fiscal policy which has received significant attention (see for instance Bussiere et al., 2017, and Bouakez et al., 2017) is higher public infrastructure spending. Top IMF officials responsible for fiscal policy issues (Gaspar et al., 2020b) recently urged policy makers to increase public investment to combat the COVID crisis and strengthen the recovery. From a policy perspective, there are at least two good reasons why such spending may be beneficial to society. First, Figure 1 shows that government investment expenditures, as share of trend GDP, has declined to historically low levels in large advanced world economies (Panel A) and the four largest euro area countries (Panel B).[2] In Germany, for example, public investment was around 5 percent of trend GDP 1980, but it has now declined in a trend-wise fashion to about 2 percent. In France, Italy and Spain there is no evident long-term trend decline; for these countries the fall in government investment occurred after the global financial crisis and/or the European debt crisis. Outside of the euro area, Japan and the US display a long-term decline in government investment with about 2 and 1.5 percentage points, respectively. For the UK and Canada we do not observe a long-term trend decline, although spending on investment in these countries dropped after the financial crisis. The fact that public investment in leading economies has been unusually low for some years implies that the marginal returns on certain types of higher spending are likely elevated. One such type of spending is public investment aimed at facilitating lower CO2 emissions in the economy and mitigating climate change risks. Second, from an economic perspective the beneficial premise of such a strategy is that it combines the benefits of providing higher demand when the economy is in a recession and raising sustainable potential output (to the extent that higher public spending increases the effective capital stock) when the economy recovers from the slump. Thus, a properly sized infrastructure spending bill could thus provide significant stimulus in both the near-

[1] In July 2020, the German government lowered the VAT tax rate but announced that the cut would last only until the end of 2020. Hence, this policy includes an announced increase in the VAT tax rate which can be thought of as an unconventional fiscal policy.

[2] In Figure 1, gross fixed capital formation (GFCF) in the government sector is measured as investment in R&D, military weapons systems, transport infrastructure and public buildings such as schools and hospitals. Under the 1993 System of National Acounts (SNA) military spending on fixed assets was treated as GFCF only if they could be used for civilian purposes of production (e.g., airfields, docks, roads etc.). The 2008 SNA treats all military expenditures on fixed assets as GFCF regardless of the purpose. We divide the annual government investment series by trend GDP, approximated by an HP filtered trend with the smoothness parameter lambda set to 100 (the value generally used for annual time series). We use annual national accounts provided by OECD and backcast for some countries with data from the European Commission AMECO database.

and medium-term and be fully – or nearly – self-financed.

As the empirical evidence of the two policy options are scant in long-lasting liquidity traps, we investigate the robustness of the two strategies using New Keynesian DSGE models. Although we are completely sympathetic to examining the merits of these policies in more empirically oriented frameworks, we note that data limitations (lack of episodes of adopted policies in long-lasting liquidity traps) make such an exercise less relevant for the current situation in which central banks across the world are not expected to raise their policy rates for many years to come.[3]

Our starting point is that the gains of policies that are pursued in practice should be robust across different models, and should not be sensitive to the specifics of a given model. In this vein, we begin our analysis using a variant of the simple benchmark NK model of Eggertsson and Woodford (2003) with a fixed private capital stock. We use this model to study the effects on output and government debt of gradual sales tax hikes and increases in public infrastructure investment. Following Leeper, Walker and Yang (2010), we assume that it takes 1-6 years to complete government investment projects and that the efficiency with which public capital adds to the overall capital stock is limited. Hence, our results are not driven by unrealistic assumptions about the speed and magnitude by which a higher level of public investment adds to the effective capital stock.

Next, we move on to examining the robustness of the results in a more empirically-realistic model. In particular, we utilize a two-agent New Keynesian (TANK henceforth) model which shares many similarities with the estimated one-agent models of Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2007), but adds heterogeneity by featuring "Keynesian" hand-to-mouth agents. The inclusion of hand-to-mouth households enables our model to explain the evidence of the substantial response of household spending to the temporary US tax rebates of 2001 and 2008, documented by Johnson, Parker, and Souleles (2006) and Parker et al. (2011) using micro data from the Consumer Expenditure Survey. Debortoli and Galí (2017) argue that TANK models capture some key aspects of the dynamics in more fully-fledged HANK models (see for instance Kaplan et al., 2016), and therefore allow us to assess the redistributive effects of alternative policies, which is especially pressing to consider in the current economic crisis. Moreover, as argued by Galí, López-Salido, and Vallés (2007), the inclusion of Keynesian households can help to account for the

[3] For instance, the influential work by D'Acunto et al. (2016, 2018) does not consider the merits of a gradual sales tax increase in long-lasting liquidity traps. Moreover, there are few episodes with large changes in public infrastructure spending in which monetary policy is expected to be at its effective lower bound for a protracted period. For instance, when the Obama administration signed the ARRA stimulus bill in February 2009, financial markets only expected the Fed to keep the federal funds rate at its lower bound for less than one year.

positive response of aggregate private consumption to a government spending shock documented in structural VAR studies by for example Blanchard and Perotti (2002) and Perotti (2007); more generally, "Keynesian" hand-to-mouth agents increase the multiplier by amplifying the response of the potential real interest rate.

Our main findings are as follows. First, we find that the beneficial effect of a gradual increase in the sales tax is not robust across various model specifications unless labor income taxes are adjusted aggressively simultaneously to maintain a balanced budget. Specifically, a gradual tax hike strategy works well in the plain-vanilla sticky price model, but when a TANK economy with endogenous capital accumulation is considered, such a policy strategy is contractionary in a long-lived liquidity trap unless labor income taxes are cut aggressively to balance the deficit. Moreover, a gradual tax hike strategy on its own has strong adverse effects on the consumption of hand-to-mouth households. This finding suggests that the benefits of unconventional fiscal policy is contingent on a "grand bargain" involving adjusting several tax rates simultaneously. This is politically hard to achieve, and may therefore be a risky strategy.

On the other hand, conventional fiscal policy – in the form of higher public infrastructure spending (roads, public transportation, health care, education programs, etc.) – has robust benign effects across the variations of the models in a long-lasting liquidity trap. In a long-lasting liquidity trap, the stimulative effects of higher public spending are sufficiently large that labor income taxes do not have to be raised much at all to balance the budget in the near term; thus the effects of higher spending are invariant to an exact balanced budget assumption. Importantly, we find that the benign effects are reasonably robust to how quickly investment becomes productive and the extent to which it is productive in the sense of enhancing the economy's capital stock. Moreover, this strategy has beneficial distributional effects: by creating more jobs in the economy it boosts the labor income of hand-to-mouth workers and their consumption more than savers' consumption. The only adverse impact is that private capital is crowded out somewhat in the longer term when the economy is recovering from the recession.[4] Our conclusion is that fiscal reforms should therefore consider public investment opportunities and not exclusively rely on tax policies to stimulate growth.

Our paper contributes to a growing literature on the macroeconomic effects of alternative fiscal reforms. Apart from the papers already mentioned, a recent paper by Bussière et al. (2017) analyzes which fiscal reforms could be useful for stimulating growth in a high-debt environment. They focus on budget-neutral reforms – which would correspond to our simulations with aggressive

[4] This follows from our Cobb-Douglas production function assumption between private and public capital, although the crowding out of private capital is smaller in a long-lasting liquidity trap.

tax rules – and show that higher government investment, funded by increases of the labor income and consumption taxes, would be more beneficial for output growth than a fiscal devaluation (cuts of labor and capital taxes financed by hikes in the consumption tax). Even so, they do not consider the case of unconventional fiscal policy. Bouakez et al. (2017) shows that time-to-build plays a key role in generating a high multiplier of government investment in a liquidity trap. While the disinflationary effect of this policy occurs after the liquidity trap has ended because of time-to-build, its positive impact on household wealth amplifies the increase in aggregate demand and the fall in the real interest rate during the trap. The recent literature has also emphasized the role of the timing of impulses to government investment in a liquidity trap. Le Moigne et al. (2016) show that when part of the higher investment spending occurs after the zero lower bound (ZLB) incident has ended, the private capital stock is reduced and the positive impact of the impetus to public investment is correspondingly smaller.

In a recent paper Boehm (2016) shows that the public investment output multiplier is significantly smaller when government investment is based on a specific investment good and monetary policy is unconstrained. To examine the robustness of our results, we thus set up a two-sector model with durables and non-durables, assuming that durables are used exclusively for government investment. In this more articulate model, the government investment output multiplier is moderated somewhat relative to our benchmark one-sector model in normal times when monetary policy respondes whereas it remains elevated in a liquidity trap. Our findings support Boehm (2019) who provides empirical evidence (based on local projection methods) of a sizable government investment output multiplier at the ZLB. Cox et al. (2019) also show that sectoral heterogeneity matters and emphasize in particular that government spending is biased toward goods with a higher degree of stickiness and that this supports a high output multiplier in a two-sector framework.

The remainder of this paper is organized as follows. Section 2 develops and analyses a stylized New Keynesian model with variations in sales taxes and public capital in which labor income taxes are used to stabilize government debt. The results for this model are then discussed in Section 3. In Section 4, we examine the robustness of the results in the more empirically-realistic TANK model with capital. Finally, Section 5 concludes. Appendix A and Appendix B contain more details on the models, while Appendix C provides additional robustness results for a model with durable goods.

2. A Stylized New Keynesian Model

As in Eggertsson and Woodford (2003), we use a standard log-linearized version of the New Keynesian model that imposes a zero bound constraint on interest rates. The model is very similar to the simple model with distortionary labor income taxes analyzed by Erceg and Lindé (2014) with fixed private capital, which here is extended to allow for sales taxes and public infrastructure investment.

2.1. The Model

We start out by characterizing the model without public capital and discuss the effects of changes in the sales tax We then describe how we introduce public capital accumulation and examine the effects of infrastructure investment (in Section 3.2). The key equations of the model without public capital are:

$$x_t = x_{t+1|t} - \hat{\sigma}(i_t - \pi_{t+1|t} - r_t^{pot}), \tag{1}$$

$$\pi_t = \beta\pi_{t+1|t} + \kappa_{mc}\left[\phi_{mc}x_t + \tfrac{1}{1-\tau_N}\left(\tau_{N,t} - \tau_{N,t}^{pot}\right)\right], \tag{2}$$

$$i_t = \max\left\{-i, (1-\gamma_i)\left(\gamma_\pi\pi_t + \gamma_x x_t\right) + \gamma_i i_{t-1}\right\}, \tag{3}$$

$$y_t^{pot} = \frac{1}{\phi_{mc}\hat{\sigma}}[g_y g_t + (1-g_y)\nu_c\nu_t - \frac{\hat{\sigma}}{1-\tau_N}\tau_{N,t}^{pot} - \frac{\hat{\sigma}}{1+\tau_C}\tau_{C,t}], \tag{4}$$

$$r_t^{pot} = \frac{1}{\hat{\sigma}}\mathrm{E}_t\Delta y_{t+1}^{pot} - \frac{g_y}{\hat{\sigma}}\mathrm{E}_t\Delta g_{t+1} - \frac{1-g_y}{\hat{\sigma}}\nu\mathrm{E}_t\Delta\nu_{t+1} + \frac{1}{1+\tau_c}\mathrm{E}_t\Delta\tau_{C,t+1},, \tag{5}$$

where $\hat{\sigma}$, κ_{mc}, and ϕ_{mc} are composite parameters defined as:

$$\hat{\sigma} = \sigma(1-g_y)(1-\nu_c), \tag{6}$$

$$\kappa_{mc} = \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p\left(1+\theta_p\epsilon_p\right)}, \tag{7}$$

$$\phi_{mc} = \frac{\chi}{1-\alpha} + \frac{1}{\hat{\sigma}} + \frac{\alpha}{1-\alpha}. \tag{8}$$

All variables are measured as percentage or percentage point deviations from their steady state level.[5]

[5] We use the notation $y_{t+j|t}$ to denote the conditional expectation of a variable y at period $t+j$ based on information available at t, i.e., $y_{t+j|t} = \mathrm{E}_t y_{t+j}$. The superscript 'pot' denotes the level of a variable that would prevail under completely flexible prices, e.g., y_t^{pot} is potential output. See Appendix A for the model derivation.

Equation (1) expresses the "New Keynesian" IS curve in terms of the output and real interest rate gaps. Thus, the output gap x_t depends inversely on the deviation of the real interest rate $(i_t - \pi_{t+1|t})$ from its potential rate r_t^{pot}, as well as on the expected output gap in the following period. The parameter $\hat{\sigma}$ determines the sensitivity of the output gap to the real interest rate; as indicated by (6), it depends on the household's intertemporal elasticity of substitution in consumption σ, the steady state government spending share of output g_y (c_y is the steady state consumption share, so $1 = g_y + c_y$), and a (small) adjustment factor ν_c which scales the consumption taste shock ν_t. The price-setting equation (2) specifies current inflation π_t to depend on expected inflation, the output gap and the labor-income tax gap, where the sensitivity to the latter is determined by the composite parameter $\kappa_{mc}/(1-\tau_N)$ and the sensitivity of the output gap is determined by $\kappa_{mc}\phi_{mc}$. Given the Calvo-Yun contract structure, equation (7) implies that κ_{mc} varies inversely with the mean contract duration $(\frac{1}{1-\xi_p})$. The sensitivity of marginal cost to the output gap ϕ_{mc}, equals the sum of the absolute value of the slopes of the labor supply and labor demand schedules that would prevail under flexible prices: accordingly, as seen in (8), ϕ_{mc} varies inversely with the Frisch elasticity of labor supply $\frac{1}{\chi}$, the interest-sensitivity of aggregate demand $\hat{\sigma}$, and the labor share in production $(1-\alpha)$. The policy rate i_t follows a standard interest rate rule subject to the zero lower bound (equation 3).

Equation (4) indicates that potential output y_t^{pot} depends on the sales tax $(\tau_{C,t})$ and the labor income tax $(\tau_{N,t})$ and varies directly with exogenous movements in consumption demand ν_t and government spending g_t. The two latter shocks are assumed to follow AR(1) processes with the same persistence parameter ρ_ν, e.g., the taste shock follows:

$$\nu_t = \rho_\nu \nu_{t-1} + \varepsilon_{\nu,t}, \tag{9}$$

where $0 < \rho_\nu < 1$. Given the front-loaded nature of the shocks, equation (5) indicates that positive realizations of these shocks boosts the potential real interest rate (noting $\phi_{mc}\hat{\sigma} > 1$); this reflects the fact that each shock – if positive – raises the marginal utility of consumption associated with any given output level. The sales tax shock is allowed to follow a general AR(2) process, here written in error-correction form

$$\Delta\tau_{C,t} = \rho_{\tau,1}\Delta\tau_{C,t-1} - \rho_{\tau,2}\tau_{C,t-1} + \varepsilon_{C,t}. \tag{10}$$

We now turn to discussing how $\tau_{N,t}$ is determined. The government issues nominal debt as needed to finance budget deficits. Under the simplifying assumption that government debt is zero in steady state, the log-linearized government budget constraint is given by:

$$b_{G,t} = (1+r)b_{G,t-1} + g_y g_t - c_y \left[\tau_{C,t} + \tfrac{\tau_C}{c_y}\left(y_t - g_y g_t\right)\right] \tag{11}$$

$$-s_N \left[\tau_{N,t} + \frac{\tau_N}{1-\tau_N}\left(\tau_{N,t} - \tau_{N,t}^{pot}\right) + \tau_N\left(y_t + \phi_{mc}x_t\right)\right] - \tau_t, \tag{12}$$

where $b_{G,t}$ is end-of-period real annualized government debt as share of trend output, $(y_t + \phi_{mc}x_t)$ equals real labor income, τ_t is a lump-sum tax, and s_N is the steady state labor share.[6] Labor income taxes adjust according to the reaction function:

$$\tau_{N,t} - \tau_N = \varphi_b b_{G,t-1} + \varphi_{bb}\tilde{\tau}_{N,t}. \tag{13}$$

This rule has the convenient property that it can be calibrated so that it is not very aggressive by selecting a low value for φ_b (and by setting φ_{bb} equal to nil). However, by setting $\varphi_b = 0$ and $\varphi_{bb} = \frac{1}{s_N}$, and defining $\tilde{\tau}_{N,t}$ in the log-linearized goverment budget constraint (11) so that $b_{G,t} = 0$ for all possible states, i.e.

$$0 = (1+r)b_{G,t-1} + g_y g_t - c_y \left[\tau_{C,t} + \tfrac{\tau_C}{c_y}\left(y_t - g_y g_t\right)\right] \tag{14}$$

$$-s_N \left[\tilde{\tau}_{N,t} + \frac{\tau_N}{1-\tau_N}\left(\tilde{\tau}_{N,t} - \tau_{N,t}^{pot}\right) + \tau_N(y_t + \phi_{mc}x_t)\right] - \tau_t, \tag{15}$$

then $\tau_{N,t}$ in eq. (13) mimics an aggressive "balanced budget" rule, because it implies government debt in eq. (11) remains constant (i.e. $b_{G,t} = 0 \; \forall t$). Finally, note that the complete model includes versions of eqs. (11) - (14) which holds in the notional economy with flexible prices, determining $b_{G,t}^{pot}$, $\tau_{N,t}^{pot}$, and $\tilde{\tau}_{N,t}^{pot}$, respectively.

2.2. Parameterization

Our benchmark calibration is fairly standard at a quarterly frequency; intended to be relevant for the United States and the euro area. We set the discount factor $\beta = 0.995$, and the steady state net inflation rate $\pi = .005$; this implies a steady state interest rate of $i = .01$ (i.e., four percent at an annualized rate). We set the intertemporal substitution elasticity $\sigma = 1$ (log utility), the capital share parameter $\alpha = 0.3$, the Frisch elasticity of labor supply $\frac{1}{\chi} = 0.4$, and the scale

[6] In (11), real government debt $b_{G,t}$ and real transfers τ_t are defined as a share of steady state GDP and expressed as percentage point deviations from their steady state values. That is, $b_{G,t} = \left(\frac{B_{G,t}}{P_t Y}\right) - b_G$, where $B_{G,t}$ is nominal government debt, P_t is the price level, and Y is real steady state output; and similarly, $\tau_t = \left(\frac{T_t}{P_t Y}\right) - \tau$. Because of our simplifying assumption that $b_G = 0$, a time-varying real interest rate does not figure in eq. (11). In the full model analyzed in Section 4, we allow for positive steady state government debt, and hence a role for time-varying debt service costs.

parameter on the consumption taste shock $\nu_c = 0.01$. Following recent US evidence in Del Negro, Giannoni and Schorfheide (2015) and Lindé, Smets and Wouters (2016), and euro area evidence in Blanchard, Erceg and Lindé (2016) we select $\xi_p = .89$ and the Kimball curvature parameter $\epsilon_p = 10$ so that the results are not contingent on counterfactually large movements in actual and expected inflation. With this choice and a net markup $\theta_p = 0.2$, the Phillips Curve slope $\kappa_{mc} = .005$, and the sensitivity of inflation to the output gap, $\kappa_{mc}\phi_{mc}$, equals 0.025.

We assume that monetary policy follows a standard simple policy rule by setting $\gamma_i = 0.7$, $\gamma_\pi = 2.5$ and $\gamma_x = 0.25$. In A.2 we present alternative results when monetary policy completely stabilize inflation and the output gap in the absence of a zero bound constraint, which can be regarded as a limiting case in which the coefficients on inflation, γ_π, and the output gap, γ_x, in the interest rate reaction function become arbitrarily large.

The government share of steady state output $g_y = 0.23$ (roughly in line with total government spending in the euro area and the United States), and the sales tax $\tau_C = 0.10$ in the steady state (as a compromise between the zero federal sales tax in the United States and the 20 percent rate in place in many euro area economies). By making the simplifying assumption that the government debt ratio is nil in the steady state and that $\tau = -.06$ (so that net transfers equal 6 percent of GDP), equation (11) implies that τ_N equals about 37 percent in the steady state.[7] When we consider a non-aggressive tax rule (13), we set the parameter φ_b equal to .01 and $\varphi_{bb} = 0$, which implies that the response of the labor income tax rate to changes in government debt is very moderate in the first couple of years following a shock (so that almost all the variation in tax revenues stems from fluctuations in hours worked). For the balanced budget rule, we set $\varphi_{bb} = \frac{1}{s_N}$ and $\varphi_b = 0$ as explained previously. Obviously, this rule will feature larger movements in $\tau_{N,t}$ in response to various shocks to keep government debt unchanged. Finally, the consumption preference shock ν_t is assumed to follow an AR(1) process with persistence of $\rho_\nu = 0.9$ in equation (9).

3. Results with the Stylized Model

In this section, we report the results in the stylized model. We begin by studying responses to a gradual sales tax hike before moving onto studying the effects of public investment.

[7] We study the robustness of the results when allowing for a steady state debt share of 100 percent of GDP in the workhorse model in Section 4.

3.1. Impulse Responses to a Gradual Sales Tax Hike

In Figure 2, we show the effects of an increase in the sales tax $\tau_{C,t}$ in normal times and in a three year liquidity trap. A three-year liquidity trap is roughly the current projection in financial markets of how long the European Central Bank (ECB) is expected to keep its key policy rate at its effective lower bound (here zero), and is generated in the model by assuming that an adverse consumption demand shock ν_t eq. (9) hits the economy.[8] Following the insights in Corriea et al. (2013), we assume that the sales tax $\tau_{C,t}$ is raised gradually, with the increase peaking at about 1.3 percent after 12 quarters.[9] By assuming that $\tau_{C,t}$ peaks the quarter before the economy exits the liquidity trap, we maximize its economic impact. With our calibration of the consumption-output ratio in the steady state, a 1.3 percent hike in $\tau_{C,t}$ is consistent with generating 1 percent higher sales tax revenues as a share of GDP if consumption (and output) remain unchanged.

In the figure, the left-hand column reports the results when the labor income tax adjusts gradually, i.e. $\varphi_b = 0.01$ and $\varphi_{bb} = 0$ in eq. (13), whereas the right-hand column reports the results under complete debt stabilization (i.e. $\varphi_b = 0$ and $\varphi_{bb} = 1/s_N$). As expected from Correia et al. (2013), we see from the left-hand column that the sales tax hike stimulates economic activity in a long-lasting liquidity trap, by causing the actual real rate to fall while the potential real rate rises. However, in normal times when monetary policy would respond to the higher sales tax path by raising the policy rate, we see that the impact on economic activity is much more muted. As labor income taxes are assumed to respond very slowly, the higher tax rate and consumption profile implies that tax revenues increase considerably, and government debt falls by roughly 5 percent after 5 years.

The results are qualitatively similar when labor income taxes respond aggressively to keep government debt unchanged (second from bottom right-hand panel), but there are some important differences which deserve to be highlighted. In a liquidity trap, the labor income tax rate has to be cut more aggressively compared with normal times to stabilize debt, and this causes output, depicted in the top right-hand panel, to rise more when the labor tax rule is aggressive. The finding that output rises more when labor income taxes are aggressively cut runs counter to the wisdom from Eggertsson (2011) and Christiano, Eichenbaum and Rebelo (2011), who both argue that *a hike in the labor tax rate* stimulates output in a liquidity trap. However, these authors analyze the impact of *exogenous* shifts in the labor income tax and they therefore do not allow for the effects of

[8] In September 2020 market expectations of future short-term interest rates suggest that policy interest rates are expected to remain unchanged for three years in both the euro area and the United States.
[9] This is achieved by setting $\rho_{\tau,1} = 0.8$ and $\rho_{\tau,2} = 0.001$ in equation (10).

endogenous tax gaps on inflation – i.e. the term $\frac{\kappa_{mc}}{1-\tau_N}\left(\tau_{N,t}-\tau_{N,t}^{pot}\right)$ in the Phillps curve (2) – and the effects an endogenous tax rule has on the potential real rate r_t^{pot} through its effects on potential output y_t^{pot} in eq. (4). An aggressive tax rule induces a persistent negative tax-wedge $\tau_{N,t}-\tau_{N,t}^{pot}$ and from the Phillips curve (2) this mutes the impact on inflation which can be seen by comparing the inflation response for the non-aggressive and aggressive tax rule panels in Figure 2. So, what drives the elevated output response under the balanced-budget labor tax rule is the benign impact on expected potential output growth (compare the black-dashed lines in the left- and right-hand panels for output), which in turn helps to elevate the path for r_t^{pot} according to equation (5).[10]

3.2. Impulse Responses to Higher Government Investment

In this subsection, we examine the dynamic effects of higher levels of government investment. Before turning to the results, we briefly describe how government investment builds capital in the model.

3.2.1. Extending the model with public investment

So far, we have assumed the aggregate capital stock was fixed. We now relax this assumption and assume that

$$Y_t = Z_t \left(K_t^{tot}\right)^{\alpha} N_t^{1-\alpha}, \tag{16}$$

where

$$K_t^{tot} = \left(K_P\right)^{\vartheta} \left(K_{G,t}\right)^{1-\vartheta}. \tag{17}$$

Eq. (17) implies that the effective capital stock, K_t^{tot}, is affected by the government capital stock $K_{G,t}$. Following Leeper, Walker and Yang (2010), we assume that the direct impact on Y_t of a one percent increase in $K_{G,t}$ equals 5 percent.[11] Given our choice of α (.3), we calibrate ϑ to .833 in order to match this output elasticity ($(1-\vartheta)\,\alpha = .05$). The law of motion for public capital $K_{G,t}$ is standard:

$$K_{G,t} = (1-\delta_G)K_{G,t-1} + I_{G,t},$$

where we set $\delta_G = .02$. In line with how the real world works, we assume building the public capital stock takes time so expenses on public capital in period t, $G_{I,t}$, only turns into effective investment into the public capital stock $I_{G,t}$ with some lags:

$$I_{G,t} = \frac{1}{6}\left(G_{I,t-4} + G_{I,t-8} + G_{I,t-12} + G_{I,t-16} + G_{I,t-20} + G_{I,t-24}\right). \tag{18}$$

[10] The positive impact on potential output of a permanent increase in $\tau_{C,t}$ financed by a permanent decline in $\tau_{N,t}$ stems from the fact that sales taxes are less distortionary than labor income taxes in our model. This is a standard finding in the literature, see for example Chamley (1985) and Judd (1986) and Chari, Christiano and Kehoe (1994).

[11] The value of 0.05 is the lower value they choose for this elasticity, the other being 0.10.

The specification in eq. (18) implies a uniform distribution of project completion duration between 1 and 6 years. Leeper, Walker and Yang (2010) assumed a three-year time to build. Obviously, we bear in mind that some projects may be relatively fast to complete, like repairing or extending a bridge or building, whereas more major projects, for example building a new freeway or significantly increase the capacity in the electricity nets, take longer time to complete. Since our choice is arbitrary, we examine the sensitivity of our specification of $I_{G,t}$ by considering faster and slower average completion times. In addition, we examine the sensitivity of our results to the parameter ϑ.

In the log-linearized version of the model, all the key equations (1)-(5) remain unaltered, except the equation for y_t^{pot} which now becomes

$$y_t^{pot} = \frac{1}{\varphi_{mc}} \left[\frac{g_y}{\hat{\sigma}} g_t + \frac{1}{\hat{\sigma}} (1 - g_y) \nu_c \nu_t - \frac{1}{1 - \tau_N} \tau_{N,t} - \frac{1}{1 + \tau_C} \tau_{C,t} + \frac{1 + \chi}{1 - \alpha} \left(z_t + \alpha (1 - \vartheta) k_{G,t} \right) \right]. \tag{19}$$

In eq. (19), it is important to recognize that total government spending (in log-linearized terms) now equals

$$g_t = g_C g_{Ct} + g_I g_{I,t},$$

where g_{Ct} is government consumption (in percent deviation from steady state) and $g_C = G_C/G$ and $g_I = 1 - g_C$. Since $g_y = 0.23$, and Figure 1 suggests that the public investment share of GDP equals about 4 percent in many large economies before the GFC, we set $g_C = 0.83$, so $g_I = 0.17$ (so that $g_y \times g_I = 0.04$).

3.2.2. Results

In Figure 3, we show the effects of an increase in government investment $g_{I,t}$ in normal times and in a 12-quarter liquidity trap. We assume a path with a constant increase of 1 percent of baseline GDP during 11 quarters followed by a gradual phasing-out from the 12th quarter onward with a root of 0.9. This path is motivated by the fact that more resources must be spent early on in projects, but once the projects become completed fewer and fewer resources need to be spent. Again, we compare the cases with non-aggressive (left-hand column) and aggressive (right-hand column) labor income tax rule.

Under a non-aggressive tax rule, higher public investment (e.g. in infrastructure) is more expansionary in a liquidity trap than in normal times as it raises aggregate demand and inflation expectations. Given a nominal interest rate stuck at zero, higher inflation expectations lead to the actual real interest rate falling sharply, something which does not happen in normal times. On the other hand, while the actual rate falls during the stimulus period (i.e. the first 2.5 years), the potential real interest rate, r_t^{pot}, remains unchanged and does not start to rise until the phasing-out period (from quarter 11 onwards). This happens because in the notional flexible price equilibrium the gradual phasing-out of government investment induces an upward path for private consumption (see eq. 5). The resulting negative gap between the actual real interest rate and its potential level boosts the output gap, by more than 1% in the short run (output shown in the upper left-hand panel rises by more than 1.5 percent initially, given the small response of potential output under a non-aggressive tax rule). We also notice that the fiscal stimulus is self-financed in a liquidity trap when the tax rule is not aggressive; the labor income tax is almost unchanged and the additional tax revenues induce a persistent yet temporary decline in government debt of around 1% of GDP.

Turning to the results with the balanced-budget tax rule, we see that output increases around 1 percent initially in a liquidity trap. The smaller effect is related to the fiscal rule. With an aggressive tax rule, the government uses extra tax receipts to cut the labor income tax, and in a liquidity trap, these tax cuts create deflationary pressures which moderate the real interest rate decline and accordingly the boost to output. When monetary policy is unconstrained by the effective lower bound (red dotted lines), the initial effects on output are slightly negative before turning positive as the aggressive labor income tax hikes exert a more negative drag on the economy than the boost to demand. Only when enough projects have been completed and the public capital stock and potential output have risen sufficiently to enable labor income taxes to fall, do we see that output turns positive and the effects are close to those obtained under the non-aggressive rule.

In Figure 4, we examine the robustness of a hike in government investment under a non-aggressive tax rule for four alternative assumptions: (i) public investment is not productive at all; (ii) public investment adds more to the effective capital stock than in our baseline; (iii) all public infrastructure is already productive after 1 to 2 years; (iv) public infrastructure does not become productive until after 5 to 10 years. We also report our baseline results (first row). As discussed by Bouakez et al. (2017), productive government spending has two effects on future marginal costs absent from the non-productive case: a positive demand-side effect arising from the increase in permanent income; a negative supply-side effect generated by the future increase in the marginal productivity of inputs. In a liquidity trap, if the demand (supply) effect dominates, inflation expectations will be higher (resp. lower), the real interest rate will fall more (less) and, hence, output will also increase more (less). Here, the positive demand-side effect generally dominates for the large set of assumptions that we examine: for our benchmark calibration as well as for alternative cases (ii) and (iii), we find that the output response is amplified compared with the unproductive case (i). Assuming longer time-to-build (case iv) reduces permanent income and hence demand somewhat relative to our baseline calibration.

To sum up: in a liquidity trap, we find that higher public investment stimulates the economy, even in a country which must run a balanced budget. Outside of a liquidity trap, the overall effect is less favorable, especially if the fiscal space to sustain a short-run deficit is limited. Next, we examine the robustness of our findings in a model with endogenous private capital.

4. Analysis in a TANK Model with Endogenous Private Capital

In this section, we examine how our results hold up in an empirically realistic framework with endogenous private capital accumulation. The core of the model we use is a close variant of the models developed and estimated by Christiano, Eichenbaum and Evans (2005), CEE hereafter, and Smets and Wouters (2003, 2007), SW hereafter. CEE show that their model can account well for the dynamic effects of monetary policy innovations during the post-war period. SW consider a much broader set of shocks, and argue that their model – which is estimated by Bayesian methods – is able to fit many key features of US and euro area-business cycles.

We depart from the CEE/SW environment in two substantive ways. First, we introduce heterogeneity and work with a two-agent (TANK) framework by assuming that a non-zero proportion of the households are "Keynesian", and simply consume their current after-tax income. Galí, López-Salido and Vallés (2007) show that the inclusion of non-Ricardian households helps account for structural VAR evidence indicating that aggregate private consumption rises in response to higher government spending, and also allows their model to generate a higher spending multiplier. Second, we allow for a richer modeling of fiscal policy, as outlined in more detail below.

In terms of parameterization, we set the share of Keynesian households in the economy to about 0.5, implying that they account for about 25 percent of aggregate private consumption in the steady state. However, we also report some results from a CEE/SW-type specification to help gauge sensitivity to the TANK framework. Given that most of the model's features are now standard, we relegate many details about the model, solution method, and calibration to Appendix B.[12] Nonetheless, it is important to highlight two features. First, in the model's fiscal block,

[12] We work with log-linearized equations, apart from imposing the zero lower bound on policy rates when solving the model. Given that we examine model dynamics that are not close to the steady state, an important extension of our work would be to solve the model nonlinearly.

government revenue is assumed to be derived from taxes on consumption, labor and capital.[13] While the sales tax rate and public investment vary exogenously, we will, following the analysis with the stylized model in Section 2, start out by assuming that labor income tax follows the rule:

$$\tau_{N,t}-\tau_N=\varphi_\tau\left(\tau_{N,t-1}-\tau_N\right)+\left(1-\varphi_\tau\right)\left[\varphi_b\left(\tilde{b}_{G,t-1}-\tilde{b}_G\right)+\varphi_{bb}\tilde{\tau}_{N,t}\right], \tag{20}$$

where $\tilde{b}_{G,t}$ denotes debt as a share of annualized trend GDP, i.e. $\tilde{b}_{G,t}\equiv\frac{B_{G,t}}{4P_tY}$. Variables without time-subscripts denote steady state values. This rule has the convenient feature that it can be calibrated so that it exhibits substantial inertia – and is not very aggressive even in the long run - by selecting a high value for φ_τ and a relatively low value for φ_b (and by setting φ_{bb} equal to nil). However, by setting $\varphi_\tau=\varphi_b=0$ and $\varphi_{bb}=\frac{4}{s_N}$ where s_N denotes the effective steady state labor share, and defining $\tilde{\tau}_{N,t}$ in the policy rule (20) as

$$0=\tilde{b}_G\left(i_{t-1}-\pi_t\right)+\frac{1+i}{1+\pi}\tilde{b}_{G,t-1}+\frac{1}{4}\left\{\begin{array}{c} g_t-\tau_t-c_y\left(\tau_{C,t}+\tau_C c_t\right)-s_N\left(\tilde{\tau}_{N,t}+\tau_N\left(\bar{w}_t+l_t\right)\right) \\ -s_K\left[\left(r_K-\delta\right)\tau_{K,t}+\tau_K r_{K,t}+\tau_K\left(r_K-\delta\right)\left(q_t^k+k_t\right)\right]\end{array}\right\}, \tag{21}$$

this is a balanced budget rule as it ensures that end-of-period debt remains (or jumps to) steady state, i.e. $\tilde{b}_{G,t+1}=\tilde{b}_G$, in all possible states given $\tilde{b}_{G,t}$. Since the model features endogenous capital formation, we report results in Appendix B for a rule which uses the capital income tax $\tau_{K,t}$ instead of the labor tax rate to stabilize debt, and in this case $\tau_{N,t}$ in eq. (20) is replaced by $\tau_{K,t}$ and $\varphi_{bb}=\frac{4}{s_{K(r_K-\delta)}}$.

Second, our calibration of the monetary policy rule and the Calvo price and wage contract duration parameters – while within the range of empirical estimates – tilts in the direction of reducing the sensitivity of inflation to various shocks. In particular, the monetary rule assumes the policymaker responds with a fairly aggressive long-run coefficient of 2.5 on inflation, of unity on the output gap, and 0.7 on the lagged interest rate. The parameters pertaining to the pricing Phillips curve are the same as in the stylized model (see Section 2.2 for rationale), but we allow for intrinsic persistence by setting price indexation to unity ($\iota_p=1$). To calibrate the wage Phillips curve, we draw on the recent empirical estimates for the United States in Lindé et al. (2016) and Del Negro et al. (2015) and euro area evidence in Blanchard et al. (2016) and Coenen et al. (2018), and impose a sizeable yet somewhat smaller degree of wage stickiness.[14] These parameter choices are aimed at capturing the moderate and gradual response of core and expected inflation during the

[13] Given a steady state government spending share of 23 percent and debt/GDP ratio of 100 percent, the steady state tax rate on labor income is about 36 percent, on capital income 25 percent, and on consumption 10 percent.

[14] Specifically, the Kimball wage parameter $\epsilon_w=10$, the wage contract parameter $\xi_w=0.82$, the wage markup $\theta_w=1/3$, which along with a wage indexation parameter $\iota_w=1$ implies that wage inflation is about twice as responsive to the wage markup as price inflation is to the price markup.

global recession and its aftermath.

4.1. Dynamic Effects of Sales Taxes

Figure 5 shows the effects of the same gradual increase in the sales tax as in Figure 2, but now we simulate the TANK model with all of the frictions (price and wage stickiness, hand-to-mouth households, habit formation, and adjustment costs of investment). As before, the figure reports the simulation results with the non-aggressive tax rule in the left-hand column, and the aggressive balanced-budget rule in the right-hand column. As is evident from the figure, the strong expansionary effects of a gradual increase in the sales tax in a liquidity trap are not robust to the financing scheme. In particular, the strong amplification in a liquidity trap only holds when the labor income tax adjusts aggressively. In normal times, the effects are small and similar for both tax rules in the near term, whereas the effects are somewhat more positive in the medium term under an aggressive rule, basically reflecting the fact that labor taxes are more distortionary than the sales tax in the TANK model as noted previously. In a liquidity trap with a balanced-budget rule, the higher sales tax strongly benefits Keynesian households, who despite the higher sales tax can expand their consumption since they pay lower labor income tax, get a higher real wage, and work more. Consumption of optimizing households only expands modestly, as they reallocate resources to investment opportunities.

Under an aggressive tax rule, the liquidity trap results are qualitatively similar to those obtained with the stylized model: the falling real interest rate gap boosts output and inflation in the short run. The main qualitative differences are that the output response is now hump-shaped because of all the frictions included in the full model and that inflation moves less (due to slow nominal wage adjustment). Under a non-aggressive tax rule, the results in the TANK model are very different: the real interest rate does not fall, inflation remains stable and output quickly converges to its potential level, which becomes negative because of the increased distortions imposed by the higher sales tax.[15]

Which frictions are responsible for the muted effect of this unconventional fiscal policy tool in the fully-fledged model? In order to address this issue, we strip out several key features of the full TANK model to start with a formulation that is essentially identical to the stylized model in

[15] As with the stylized model in Figure A.1, we have also studied the effects of a temporary cut in the sales tax in the TANK model (see Appendix B.2). A temporary tax cut is associated with a significantly higher output multiplier (around unity for the first year) compared with the gradual sales tax hike reported in Figure 5 for the non-aggressive labor tax case (and about the same under the balanced-budget rule). However, the temporary tax multiplier is notably smaller than for public investment as we will discuss next.

Section 2. We then add the frictions back in one by one until we are back to the TANK model used to generate the results in Figure 5.

Figure 6 summarizes the results of this analysis. Panel 1 shows the results for output and inflation in the most simplified variant of the workhorse model, with only sticky prices and no intrinsic inflation persistence. The results in this variant closely mimic those obtained with the stylized model (see Figure 2). In Panel 2, we see that adding nominal wage stickiness and allowing for intrinsic persistence in the price and wage Phillips curves moderates the effect on impact on inflation but generates a somewhat more persistent inflation impulse. As regards output, these two forces cancel one another and we are left with a similar output response. When we add habit formation in consumer preferences in Panel 3, we see that the output response falls a bit on impact but becomes a bit more persistent as expected. When we add hand-to-mouth households (so using a TANK model, Panel 4) we see that the output response schedule shifts down, which lowers the inflation curve as well. Finally, adding endogenous investment causes a further slight decline in the output and inflation responses. The key quantitative difference between the stylized model in Section 2 and the TANK model in this section is thus the assumption of gradual nominal wage adjustment and Keynesian households. When nominal wage adjustment is slow, higher VAT without compensation in terms of labor income tax means a direct cut in the purchasing power of both optimizing and especially hand-to-mouth households.

In Appendix C we examine the robustness of these findings in a model expanded with durable goods. There we report that inclusion of durables results in a significant boost to economic activity and crowding-in of consumption during the first two years even under a non-aggressive tax rule. Nonetheless, the economic benefits are significantly higher if the sales tax hike is combined with a cut in labor income taxes, echoing the findings in the TANK model without durables.

Thus, in the end, we find that unconventional fiscal policy in the form of a gradual sales tax increase is not necessarily an efficient tool to stimulate economic activity. In a more realistic model, its favorable effects hinge importantly on a package of fiscal instruments, and indeed Correia et al. (2013) assume a simultaneous cut in the labor income tax. Our simulations clarify that the labor tax adjustment is critical and that the effects of a higher sales tax in isolation may not provide much stimulus.[16]

[16] In Appendix B.2, we examine the sensitivity of our baseline results when the government uses a capital income tax-based balanced-budget rule (we do not report the results in the case with a non-aggressive rule, as the effects in this case would be similar to those in Figure 5). A capital income-based balanced-budget rule implies an investment led output boost of 4 percent (nearly twice the effects under the labor tax rule in Figure 5) after a year. Nonetheless, in the longer term the capital income tax rule has strong distributional effects, by boosting the consumption of savers (optimizing households) relative to hand-to-mouth households.

4.2. Dynamic Effects of Public Investment

We now turn to study the effects of an increase in public investment. In Figure 7, we report the effects of an identical expansion of government infrastructure investment as in Figure 3. As in the stylized model in Section 3, Figure 7 shows that the expansionary impact on output is reasonably similar under both rules, albeit somewhat smaller under the aggressive tax rule. Another interesting feature of these simulations relates to the dynamics of investment: we note that the private capital stock falls in normal times when monetary policy is unconstrained. This crowding-out of private investment might at first seem surprising, as public capital acts as a technology shock and we expect a crowding-in of private investment after a positive technology shock. However, as shown by Lindé (2009), when the maximum impact of a technology shock is anticipated to happen in the future, agents find it worthwhile to postpone investment spending and initially switch their resources toward consumption and leisure because they know that labor effort and capital will become more productive in the future. Here, we get a similar crowding-out effect in the short run because of the time-to-build in the public capital stock, which makes public investment productive with a lag of 1 to 6 years. In addition, the fact that private and public capital is aggregated through a Cobb-Douglas production function (eq. 17) implies a unit elasticity which triggers crowding-out of private investment in normal times, as noted by Boehm (2019). Finally, as can be seen from the lower panels, higher public investment crowds in total consumption, and the consumption of hand-to-mouth households accounts for the biggest part of this increase. However, under a balanced-budget rule the consumption of Keynesian households falls sharply when the fiscal stimulus ends and the economy exits the liquidity trap.

Figure 8 shows that the expansionary impact is robust to alternative assumptions about how quickly and strongly public infrastructure investment contributes to the effective capital stock. Thus, relative to the stylized model, the added mechanisms in the workhorse model mainly modify the shapes of responses, which now feature some humps.

In Appendix C we examine the robustness of these findings in a model expanded with durable goods, and report that the introduction of durable goods significantly elevates the output multipliers of a same-sized increase in public investment provided that the degree of price and wage stickiness in the durables and non-durables sectors are the same. However, existing micro evidence (Bils and Klenow, 2004) suggests that price adjustment is faster for durables, and when we recalibrate the model to account for this feature we find multipliers of government investment and sales taxes similar to those reported in Figures 7 and 5. Thus, our basic conclusions hold when we extend the model with durables.

5. Conclusions

The coronavirus crisis has brought an unprecedented challenge for stabilization policy in modern times. Central banks are expected to keep their policy rates at the effective lower bound and implement unconventional policies to stabilize financial markets. Macro-prudential policies are expected to be loosened as much as possible, in light of buildup of risks over the medium and long term. Despite the large-scale measures deployed by central banks and financial supervisory authorities, sizable fiscal stimulus packages have been advocated to provide additional support to the economy. But how can Treasuries provide the most potent boost to economic activity and employment while keeping the fiscal house in order?

We have argued in this paper that in the current situation – which can arguably be described as a long-lasting liquidity trap – there is a strong argument for increasing government spending on infrastructure projects on a temporary basis. Such a policy would help to boost demand in the near term, which is useful, and elevate potential output in the longer term when the economy is recovering. By raising the employment level, it will also have desirable redistributional effects by increasing consumption relatively more for households which live hand-to-mouth. However, our analysis highlights the importance of recognizing that the marginal benefits of such stimulus may diminish substantially outside of a liquidity trap, and may eventually require financing through higher taxes.

Our analysis has also shown that it might be of interest to complement conventional fiscal policy actions by unconventional fiscal policies in the form of a gradual increase in VAT coupled with lower labor income tax to balance the budget. A gradual sales tax hike alone without lower labor income tax is unlikely to provide any sizable boost to economic activity and may even be contractionary. Moreover, if the unemployment rate is very high and a lower labor income tax increases employment at the intensive rather than the extensive margin, unconventional fiscal policy may have a negative impact on the consumption of unemployed households. If there is a risk of such an outcome, a possibility would be to combine the higher sales tax with a combination of labor income taxes and targeted transfers to unemployed households to balance the budget. The addition of targeted transfers to the policy mix would likely moderate the boost to economic activity somewhat, but would be accompanied by significant redistributional benefits.

We leave several important issues for future research. First of all, it would be interesting to extend our analysis to an open economy setting. Second, it would be of interest to study the implications for small members of currency unions. Third, there are also open questions about whether the traditional channels through which fiscal policy affects aggregate demand remain operative in a severe recession. The effectiveness of the interest rate channel might be impaired to the extent that tight credit and heavy debt burdens reduce the interest-sensitivity of households and firms. As argued by Merten and Ravn (2010), the stimulative effects of government spending may also be muted if the source of the recession is a self-fulfilling loss of confidence, reflecting the fact that the higher spending is perceived as a negative signal about the state of the economy. Conversely, various types of fiscal interventions could have a heightened impact through easing collateral constraints on borrowers, reducing precautionary savings, or by affecting financial market risk premia. From a modeling perspective, addressing some of these questions would require a non-linear stochastic framework to capture key channels through which fiscal interventions may operate in the presence of uncertainty as in Bi, Leeper, and Leith (2013).

References

Adam, Klaus, and Roberto M. Billi (2008). "Monetary Conservatism and Fiscal Policy." *Journal of Monetary Economics,* 55(8), 1376-1388.

Adolfson, Malin, Stefan Laséen, Jesper Lindé and Mattias Villani (2005). "The Role of Sticky Prices in an Open Economy DSGE Model: A Bayesian Investigation." *Journal of the European Economic Association Papers and Proceedings,* 3(2-3), 444-457.

Altig, David, Lawrence J. Christiano, Martin Eichenbaum, and Jesper Lindé (2011). "Firm-Specific Capital, Nominal Rigidities and the Business Cycle." *Review of Economic Dynamics,* 14(2), 225-247.

Bernanke, Ben, Gertler, Mark and Simon Gilchrist (1999). "The Financial Accelerator in a Quantitative Business Cycle Framework." In *Handbook of Macroeconomics*, edited by John B. Taylor and Michael Woodford, North-Holland Elsevier Science.

Bi, Huixin, Eric Leeper, and Campbell Leith (2013). "Uncertain Fiscal Consolidations." *Economic Journal* 123, F31–F63.

Bils, Mark and Peter J. Klenow (2004). "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy*, vol. 112(5), 947-985.

Blanchard, Olivier and Roberto Perotti (2002). "An Empirical Characterization of the Dynamic Effects of Changes in Government Spending and Taxes on Output." *The Quarterly Journal of Economics*, 117(4), 1329-1368.

Blanchard, Olivier, Christopher J. Erceg, and Jesper Lindé (2016). "Jump-Starting the Euro-Area Recovery: Would a Rise in Core Fiscal Spending Help the Periphery?" *NBER Macroeconomics Annual* 31, 104-182.

Boehm Christoph E. (2016). "Government Spending and Durable Goods." *CESifo Working Paper Series* 6244, CESifo.

Boehm, Christoph E. (2019). "Government consumption and investment: Does the composition of purchases affect the multiplier?" *Journal of Monetary Economics*, forthcoming.

Bouakez, Hafedh, Guillard, Michel and Jordan Roulleau-Pasdeloup (2017). "Public Investment, Time to Build, and the Zero Lower Bound." *Review of Economic Dynamics*, 23, 60-79.

Bussière, Matthieu, Ferrara, Laurent, Juillard, Michel and Daniele Siena (2017). "Can Fiscal Budget-Neutral Reforms Stimulate Growth? Model-Based Results." Banque de France Working Paper, 625.

Canova, Fabio and Evi Pappa (2011). "Fiscal Policy, Pricing Frictions and Monetary Accommodation." *Economic Policy*, 26, 555-598.

Castelletti Font, Barbara, Pierrick Clerc and Matthieu Lemoine (2017). "Should euro area countries cut taxes on labour or capital for boosting their growth?", *Banque de France Working Paper*, forthcoming.

Chamley, C. (1986). "Optimal Taxation of Capital Income in General Equilibrium with Infinite Lives", *Econometrica* 54(3), 607–622.

Chari, V. V., Lawrence J. Christiano, and Patrick J. Kehoe (1994). "Optimal Fiscal Policy in a Business Cycle Model", Journal of Political Economy 102(4), 617-652.

Christiano, Lawrence J., Martin Eichenbaum, and Charles Evans (2005). "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy*, 113(1), 1-45.

Christiano, Lawrence J., Martin Eichenbaum, and Sergio Rebelo (2009). "When is the Government Spending Multiplier Large?" *Journal of Political Economy*, 119(1), 78-121.

Christiano, Lawrence J., Roberto Motto, and Massimo Rostagno (2008). "Shocks, Structures or Monetary Policies? The Euro Area and the US After 2001." *Journal of Economic Dynamics and Control*, 32(8), 2476-2506.

Coenen, Günter, Christopher J. Erceg, Charles Freedman, Davide Furceri, Michael Kumhof, René Lalonde, Douglas Laxton, Jesper Lindé, Annabelle Mourougane, Dirk Muir, Susanna Mursula, Carlos de Resende, John Roberts, Werner Roeger, Stephen Snudden, Mathias Trabandt, and Jan in't Veld (2012). "Effects of Fiscal Stimulus in Structural Models." *American Economic Journal: Macroeconomics*, 4(1), 22–68.

Coenen, Günter, Peter Karadi, Sebastian Schmidt, and Anders Warne (2018), "The New Area-Wide Model II: An Updated Version of the ECB's Micro-Founded Model for Forecasting and Policy Analysis with a Financial Sector", ECB Working Paper Series No. 2200.

Cogan, John F., Tobias Cwik, John B. Taylor, and Volker Wieland (2010). "New Keynesian versus Old Keynesian Government Spending Multipliers." *Journal of Economic Dynamics and Control*, 34, 281-295.

Correia, Isabel, Emmanuel Farhi, Juan Pablo Nicolini, and Pedro Teles (2013), "Unconventional Fiscal Policy at the Zero Bound." *American Economic Review* 103(4), 1172-1211.

Cox, Lydia, Gernot Müller, Ernesto Pastén, Raphael Schoenle, and Michael Weber (2020), "Big G." *NBER Working Papers* No. 27034.

Davig, Troy and Eric M. Leeper (2011). "Monetary-Fiscal Policy Interactions and Fiscal Stimulus." *European Economic Review*, 55(2), 211-227.

D'Acunto, Francesco, Daniel Hoang, and Michael Weber (2016), "The Effect of Unconventional Fiscal Policy on Consumption Expenditure," NBER Working Paper No. 22563.

D'Acunto, Francesco, Daniel Hoang, and Michael Weber (2018), "Unconventional Fiscal Policy," *American Economic Review: Papers and Proceedings*, 108(5), 519-523.

Debortoli, Davide and Jordi Galí (2017), "Monetary Policy with Heterogeneous Agents: Insights from TANK models", manuscript, CREI and University of Pompeu Fabra.

Del Negro, Marco, Marc P. Giannoni, and Frank Schorfheide (2015), "Inflation in the Great Recession and New Keynesian Models", *American Economic Journal: Macroeconomics* 7(1), 168–196.

Drautzburg, Thorsten and Harald Uhlig (2011). "Fiscal Stimulus and Distortionary Taxation." NBER Working Paper Series No. 17111.

Eggertsson, Gauti and Michael Woodford (2003). "The Zero Interest-Rate Bound and Optimal Monetary Policy." *Brookings Papers on Economic Activity*, 1, 139-211.

Eggertsson, Gauti (2008). "Great Expectations and the End of the Depression." *American Economic Review*, 98(4), 1476-1516.

Eggertsson, Gauti (2010). "What Fiscal Policy Is Effective at Zero Interest Rates?" *NBER Macroeconomics Annual*, 25, 59-112.

Erceg, Christopher, Luca Guerrieri, and Christopher Gust (2006). "SIGMA: A New Open Economy Model for Policy Analysis." *Journal of International Central Banking*, 2(1), 1-50.

Erceg, Christopher and Andrew Levin (2006). "Optimal monetary policy with durable consumption goods." *Journal of Monetary Economics* 53(7), 1341-1359.

Erceg, Christopher and Jesper Lindé (2014). "Is there a Fiscal Free Lunch in a Liquidity Trap?" *Journal of the European Economic Association* 12(1), 73-107.

Fahri, Emmanuel, Gita Gopinath, and Oleg Itskhoki (2014), "Fiscal Devaluations." *Review of Economic Studies* 81(2), 725-760.

Galí, Jordi and Mark Gertler (1999). "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics*, 44, 195-220.

Galí, Jordi, Mark Gertler, and David López-Salido (2001). "European Inflation Dynamics." *European Economic Review*, 45, 1237-1270.

Galí, Jordi, David López-Salido, and Javier Vallés (2007). "Understanding the Effects of Government Spending on Consumption." *Journal of the European Economic Association*, 5(1), 227-270.

Gaspar, Vitor, Maurice Obstfeld and Ratna Sahay (2016). "Macroeconomic Management When Policy Space is Constrained: A Comprehensive, Consistent, and Coordinated Approach to Economic Policy," Staff Discussion Note 16/09, International Monetary Fund.

Gaspar, Vitor, Paolo Mauro, Catherine Pattillo, Raphael Espinoza (2020), "Public Investment for the Recovery," IMF Blog, October 5.

Gopinath, Gita (2020), "Global Liquidity Trap Requires Big Fiscal Response," Financial Times Opinion, November 3.

Hall, Robert E. (2009). "By How Much Does GDP Rise if the Government Buys More Output?" *Brookings Papers on Economic Activity*, 2, 183-231

IMF (2020), The Great Lockdown, World Economic Outlook, Spring Report (April 2020).

Johnson, David S., Jonathan A. Parker, and Nicholas S. Souleles. 2006. "Household Expenditure and the Income Tax Rebates of 2001." *American Economic Review* 96(5): 1589–1610.

Judd, K. L. (1985). "Redistributive taxation in a simple perfect foresight model", *Journal of Public Economics* 28 (1), 59–83.

Jung, Taehun, Yuki Teranishi, and Tsotumu Watanabe (2005). "Optimal Monetary Policy at the Zero-Interest-Rate Bound." *Journal of Money, Credit, and Banking*, 37(5), 813-835.

Kaplan, Greg, Benjamin Moll and Giovanni L. Violante (2016), "Monetary Policy According to HANK," NBER Working Paper Series No. 21897.

Keynes, John Maynard (1933). *The Means to Prosperity.* London: Macmillan Press.

Keynes, John Maynard (1936). *The General Theory of Employment, Interest and Money.* London: Macmillan Press.

Le Moigne Mathilde, Francesco Saraceno and Sébastien Villemot (2016). "Probably too little, certainly too late. An assessment of the Juncker investment plan." *OFCE Working Paper*, 2016-10.

Lindé, Jesper (2005). "Estimating New Keynesian Phillips Curves: A Full Information Maximum Likelihood Approach." *Journal of Monetary Economics*, 52(6), 1135-1149.

Lindé, Jesper (2009). "The effects of permanent technology shocks on hours: Can the RBC-model fit the VAR evidence?" *Journal of Economic Dynamics and Control*, 33(3), 597-613

Lindé, Jesper, Frank Smets and Rafael Wouters (2016), "Challenges for Central Banks' Macro Models", Chapter 28 in John B. Taylor and Harald Uhlig (Eds.), Handbook of Macroeconomics Vol. 2, North-Holland Elsevier Science, New York.

Mertens, Karel and Morten Ravn (2010). "Fiscal Policy in an Expectations Driven Liquidity Trap." CEPR Discussion Paper No. 7931.

Nakata, Taisuke (2012). "Optimal Monetary and Fiscal Policy with Occasionally Binding Zero Bound Constraints." Manuscript, New York University.

Parker, Jonathan A., Nicholas S. Souleles, David S. Johnson, and Robert McClelland. 2011. "Consumer Spending and the Economic Stimulus Payments of 2008." National Bureau of Economic Research Working Paper 16684.

Perotti, Roberto (2007). "In Search of the Transmission Mechanism of Fiscal Policy." *NBER Macroeconomics Annual*, 22, 169-226.

Ramey, Valerie A. (2011). "Identifying Government Spending Shocks: It's All in the Timing." *Quarterly Journal of Economics*, 126(1), 1-50.

Smets, Frank and Raf Wouters (2003). "An Estimated Stochastic Dynamic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association*, 1(5), 1123-1175.

Smets, Frank and Raf Wouters (2007). "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review*, 97(3), 586-606.

Summers, Lawrence H. (2020), "Memo to the Biden Administration on Priorities for the US Treasury," PIIE Series on Rebuilding the Global Economy, November 10.

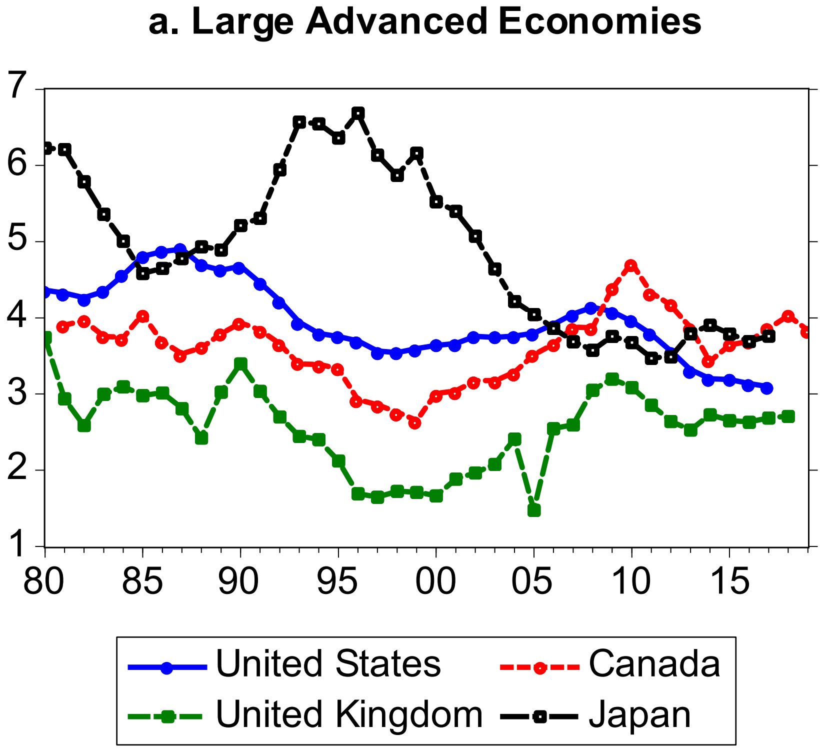
Traum, Nora and Shu-Chun S. Yang (2011). "Monetary and Fiscal Policy Interactions in the Post-War U.S." *European Economic Review*, 55(1), 140-164.

Uhlig, Harald (2010). "Some Fiscal Calculus." *American Economic Review Papers and Proceedings*, 100(2), 30-34.

Woodford, Michael (2003). *Interest and Prices.* Princeton University Press.

Woodford, Michael (2011). "Simple Analytics of the Government Spending Multiplier." *American Economic Journal: Macroeconomics*, 3(1), 1-35.

Figure 1: Government Investment for Selected Countries (% of trend GDP)



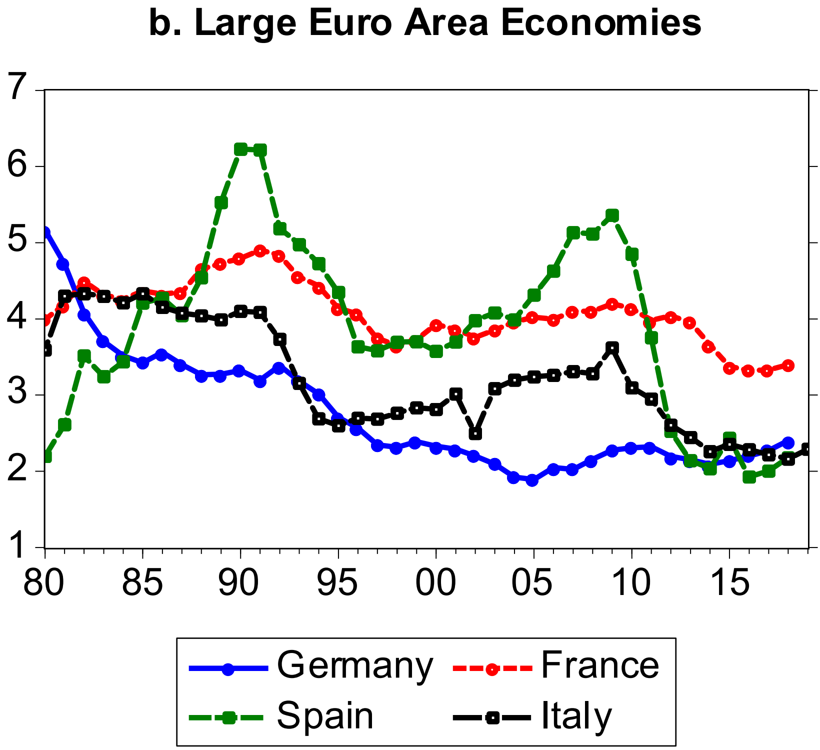


Figure 2: Gradual Sales Tax Hike in Normal Times and in a Liquidity Trap.

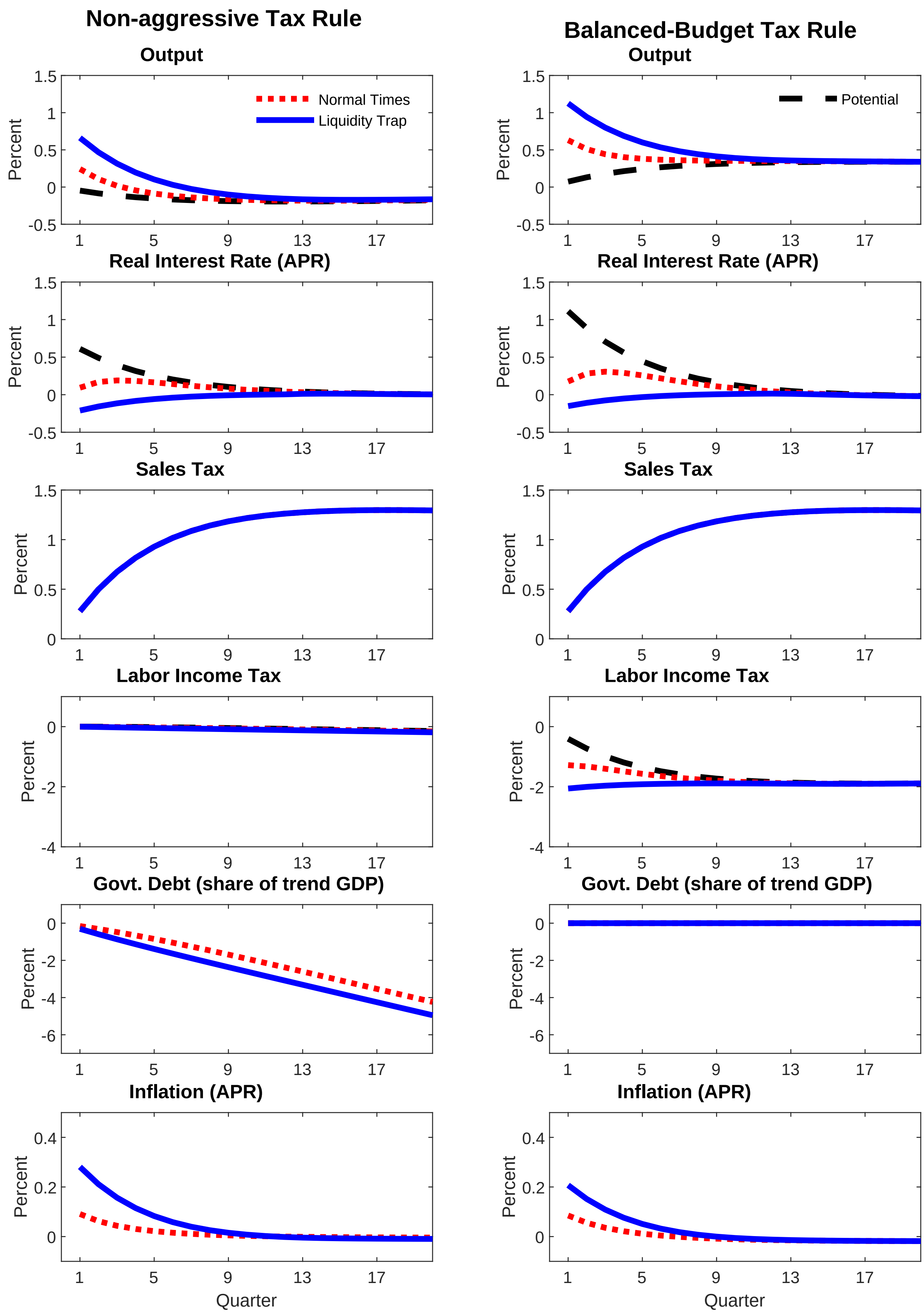


Figure 3: Higher Public Investment in Normal Times and in a Liquidity Trap.

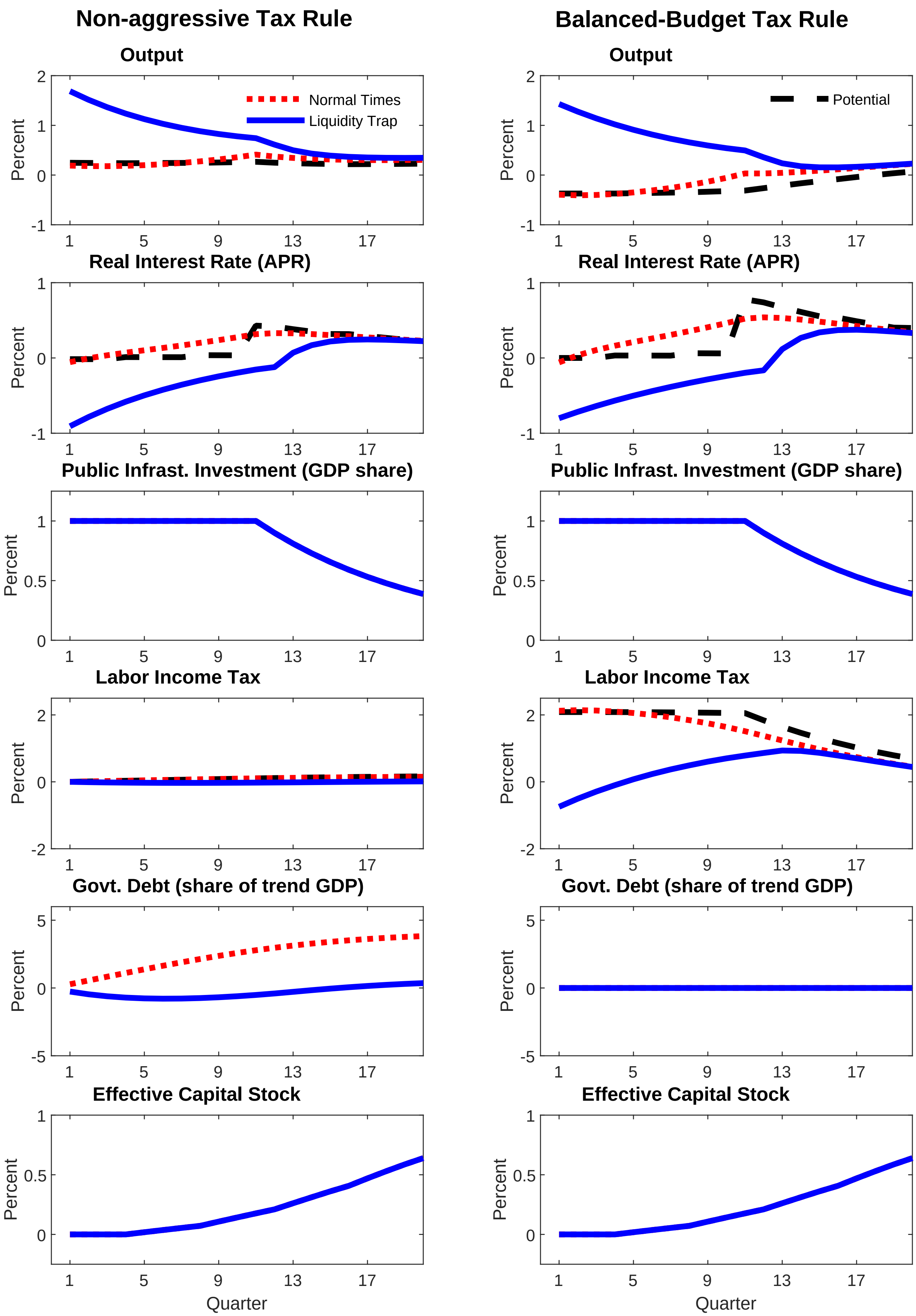


Figure 4: Robustness Analysis of Higher Public Investment.

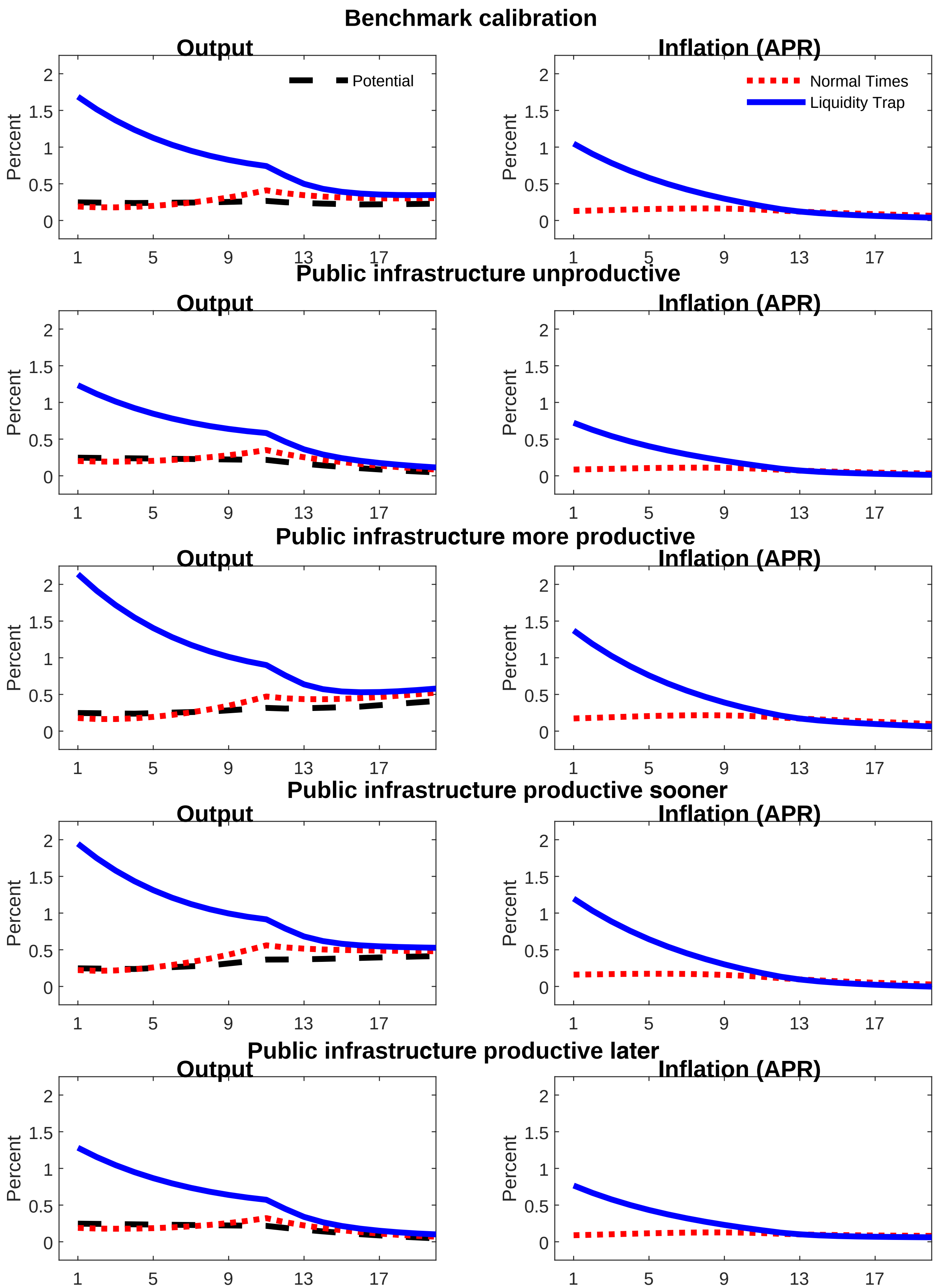


Figure 5: Sales Taxes Hike in Normal Times and in a Liquidity Trap in the TANK Model.

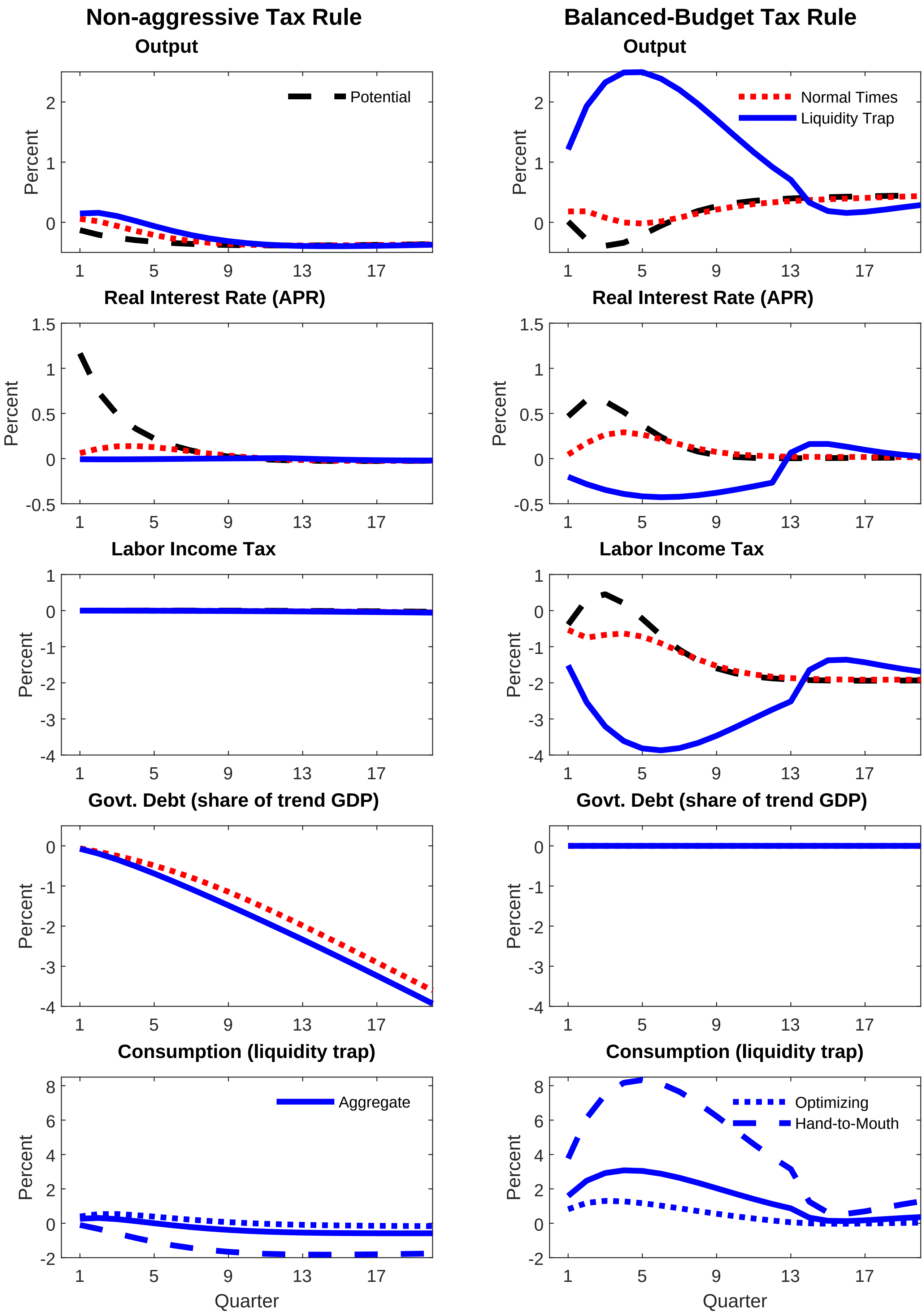


Figure 6: Sales Tax Hike in TANK Model: Understanding the Role of Various Features.

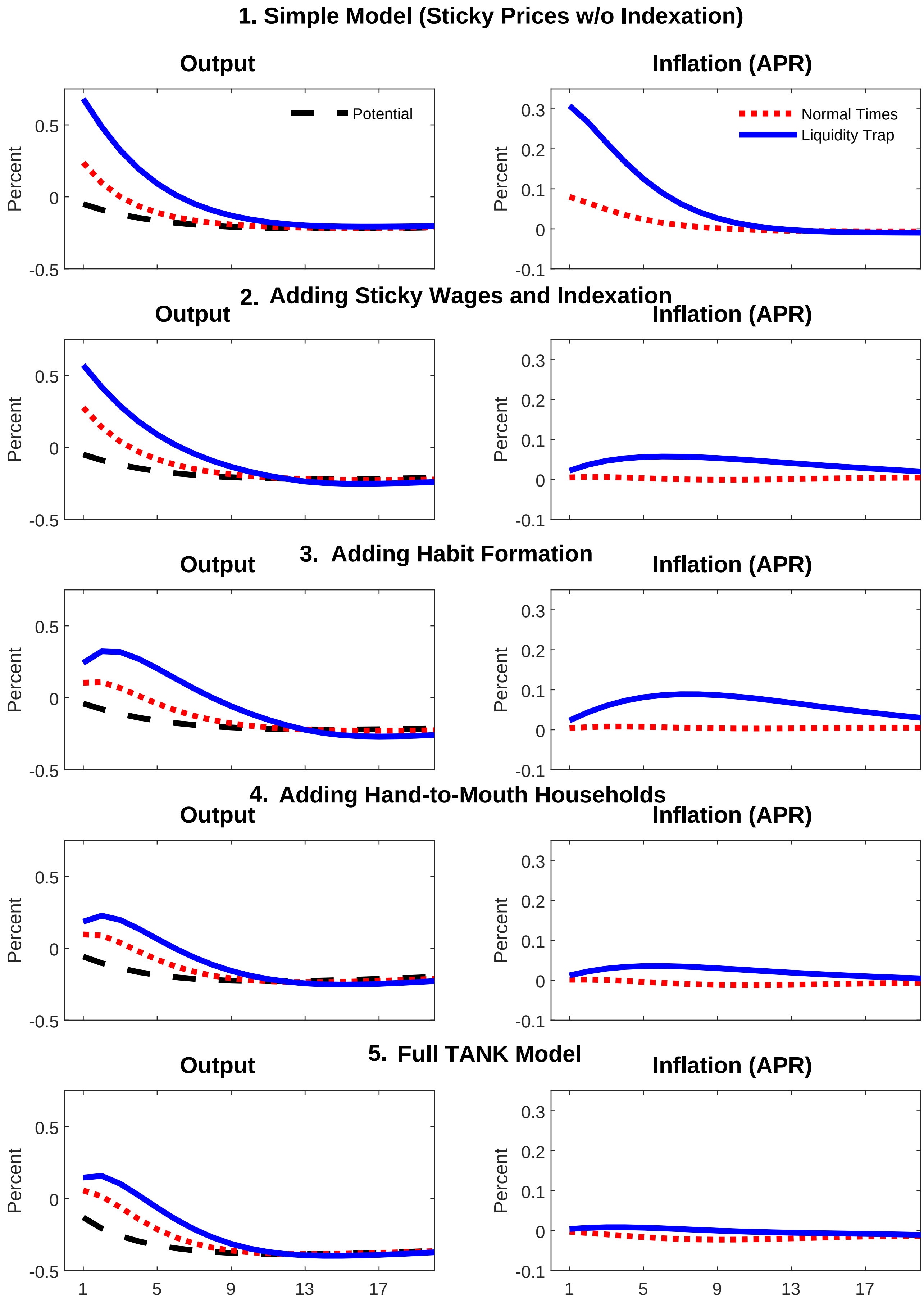


Figure 7: Higher Public Invest in Normal Times and Liquidity Trap in the TANK Model.

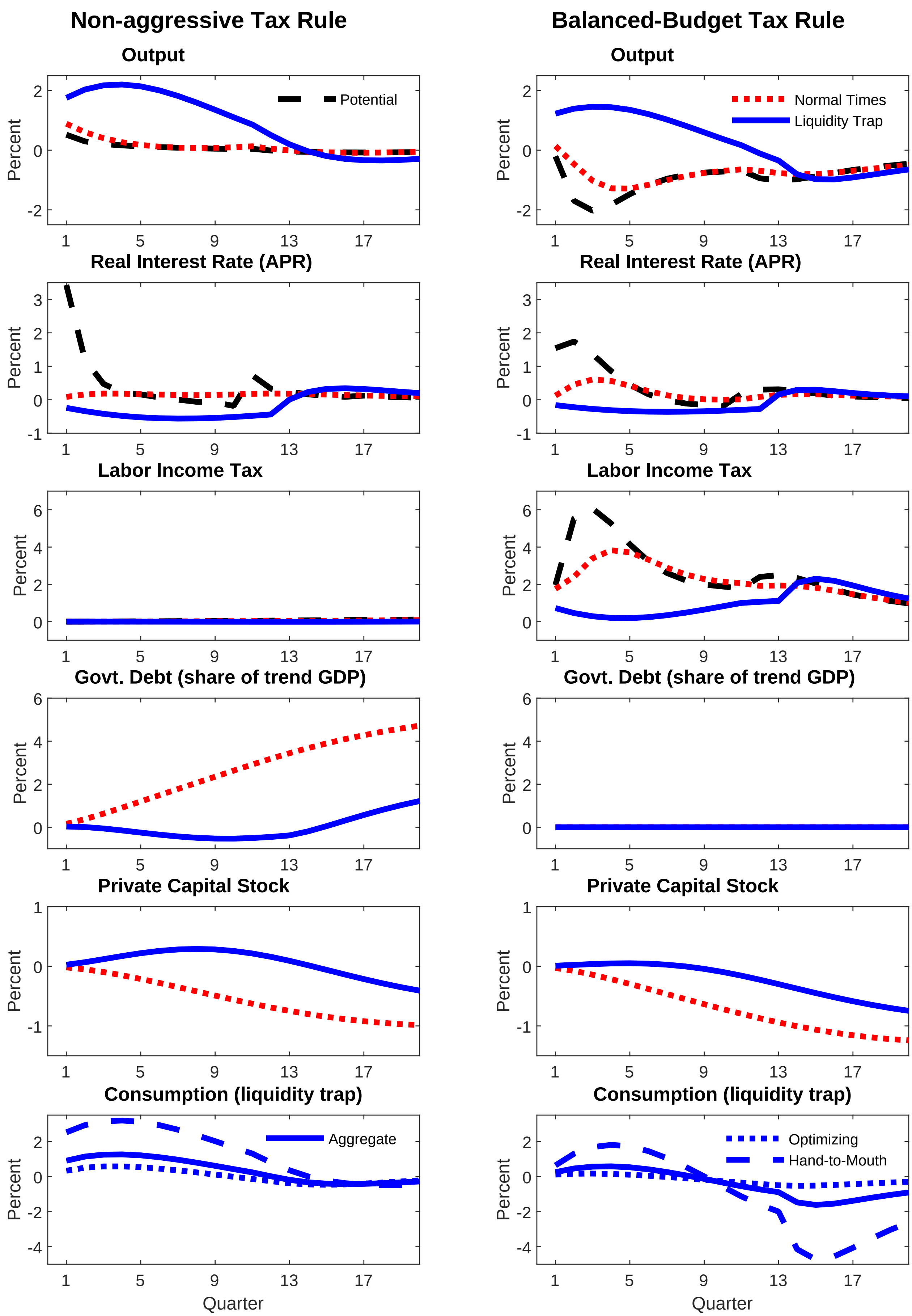
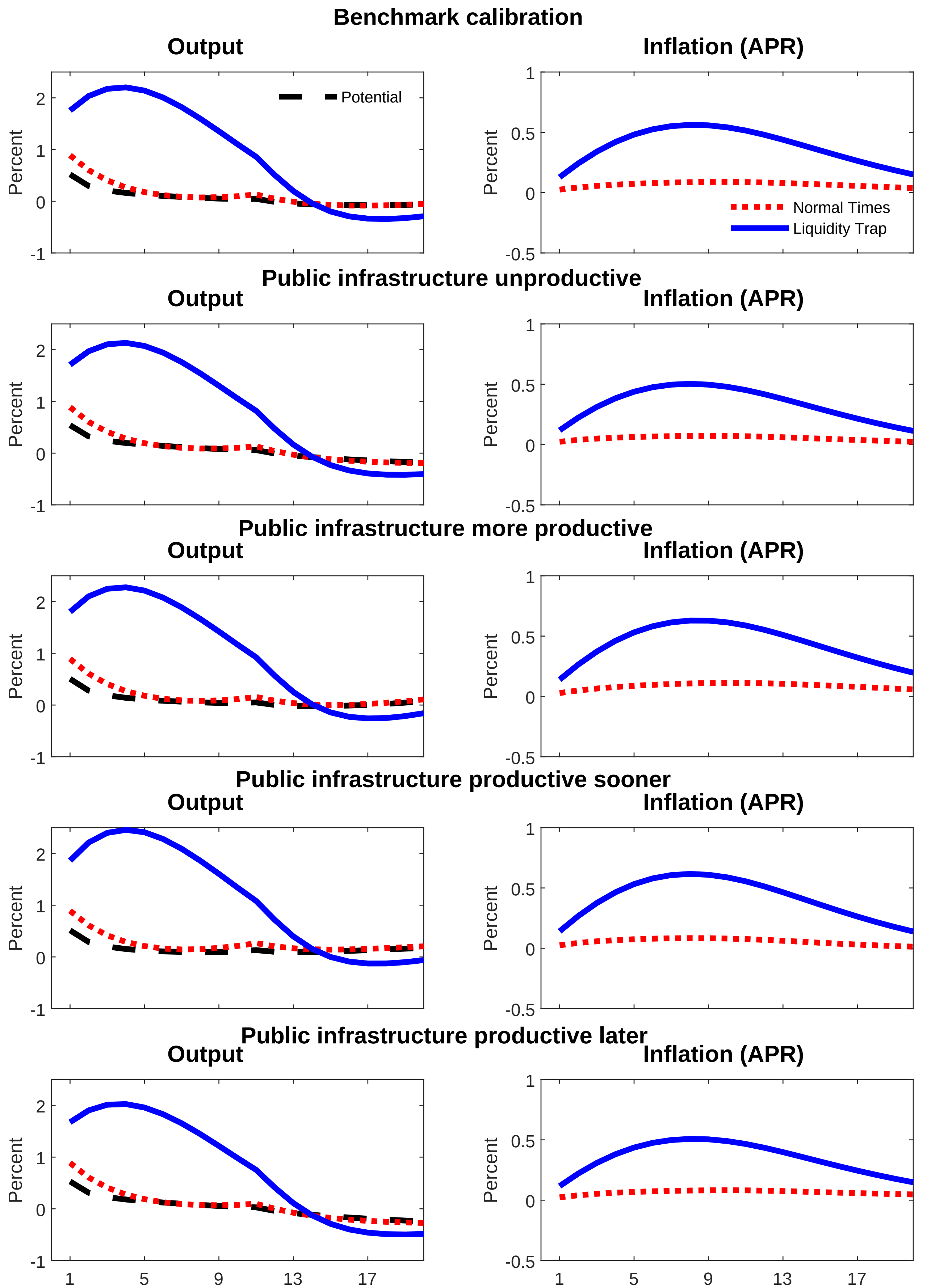


Figure 8: Robustness for Higher Public Investment in the TANK Model.



Appendix A. The Stylized New-Keynesian Model

Appendix A comprises two parts. A.1 describes and derives the model used in Section 2, including both the benchmark model with sales taxes and distortionary labor income taxes, and the extended model with public investment. A.2 contains additional results referred to in the main text.

A.1. The Model

A.1.1. Households

The utility functional for the representative household is

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{ \frac{1}{1-\frac{1}{\sigma}} \left(C_{t+j} - C\nu_{t+j}\right)^{1-\frac{1}{\sigma}} - \frac{N_{t+j}^{1+\chi}}{1+\chi} + \mu_0 F\left(\frac{MB_{t+j+1}(h)}{P_{t+j}}\right) \right\} \tag{A.1}$$

where the discount factor β satisfies $0 < \beta < 1$. The period utility function depends on the household's current consumption C_t as a deviation from a "reference level" $C\nu_{t+j}$, where a positive taste shock ν_t raises this reference level and thus the marginal utility of consumption associated with any given consumption level. The period utility function also depends inversely on hours worked N_t. Following Eggertsson and Woodford (2003), the subutility function over real balances, $F\left(\frac{MB_{t+j+1}(h)}{P_{t+j}}\right)$, is assumed to have a satiation point for $\overline{MB}/P$. Hence, inclusion of money - which is a zero nominal interest asset - provides a rationale for the zero lower bound on nominal interest rates. However, we maintain the assumptions that money is additive and that μ_0 is arbitrarily small so that changes in real money balances have negligible implications for seignorage. Together, these assumptions imply that we can disregard the implications of money for government debt and output.

The household's budget constraint in period t states that its expenditure on goods and net purchases of (zero-coupon) government bonds $B_{G,t}$ must equal its disposable income:

$$P_t\left(1+\tau_{C,t}\right)C_t + B_{G,t} + MB_{t+1} = \left(1-\tau_{N,t}\right)W_t N_t + \left(1+i_{t-1}\right)B_{G,t-1} + MB_t - T_t + \Gamma_t \tag{A.2}$$

Thus, the household purchases the final consumption good (at a price of P_t) and subject to a sales tax $\tau_{C,t}$. Each household earns after-tax labor income $\left(1-\tau_{N,t}\right)W_t N_t$ ($\tau_{N,t}$ denotes the tax rate), pays a lump-sum tax T_t (this may be regarded as net of any transfers), and receives a proportional share of the profits Γ_t of all intermediate firms.

In every period t, the household maximizes the utility functional (B.9) with respect to its consumption, labor supply and bond holdings. Forming the Lagrangian and computing the first-order conditions w.r.t. $\left[\begin{array}{ccc} C_t & N_t & B_{G,t} \end{array}\right]$, we obtain

$$\begin{aligned} (C_t - C\nu_t)^{-\frac{1}{\sigma}} - \lambda_t P_t (1+\tau_{C,t}) &= 0, \\ -N_t^{\chi} + \lambda_t (1-\tau_{N,t}) W_t &= 0, \\ -\lambda_t + \beta (1+i_t) \mathrm{E}_t \lambda_{t+1} &= 0, \end{aligned}$$

and by defining $\Lambda_t \equiv \lambda_t P_t$ as the pre-tax cost of consumption in utility units, we can rewrite the first-order conditions as

$$\begin{aligned} \Lambda_t &= \frac{(C_t - C\nu_t)^{-\frac{1}{\sigma}}}{(1+\tau_{C,t})}, \\ N_t^{\chi} &= \Lambda_t (1-\tau_{N,t}) \frac{W_t}{P_t}, \\ \Lambda_t &= \beta \mathrm{E}_t \frac{(1+i_t)}{1+\pi_{t+1}} \Lambda_{t+1}, \end{aligned}$$

where we have introduced the notation $1+\pi_{t+1} = P_{t+1}/P_t$.

By substituting out for Λ_t, we derive the consumption Euler equation

$$\frac{(C_t - C\nu_t)^{-\frac{1}{\sigma}}}{(1+\tau_{C,t})} = \beta \mathrm{E}_t \frac{(1+i_t)}{1+\pi_{t+1}} \frac{(C_{t+1} - C\nu_{t+1})^{-\frac{1}{\sigma}}}{(1+\tau_{C,t+1})}, \tag{A.3}$$

and the following labor supply schedule

$$mrs_t \equiv \frac{N_t^{\chi}}{(C_t - C\nu_t)^{-\frac{1}{\sigma}}} = \frac{(1-\tau_{N,t})}{(1+\tau_{C,t})} \frac{W_t}{P_t}. \tag{A.4}$$

(A.3) and (A.4) are the key equations for the household side of the model.

A.1.2. Firms

We assume a familiar setting with a continuum of monopolistically competitive firms to rationalize Calvo-style price stickiness. The framework in the stylized model is identical to that described below in the full model with capital (Appendix B.1.1), with two important exceptions. First, aggregate private capital is assumed to be fixed, so that aggregate production is given by

$$\begin{aligned} Y_t &= Z_t \left(K_t^{tot}\right)^{\alpha} N_t^{1-\alpha}, && \text{(A.5)} \\ K_t^{tot} &= \left(K^P\right)^{\vartheta} \left(K_t^G\right)^{1-\vartheta}. && \text{(A.6)} \end{aligned}$$

where we define the accumulation of government capital K_t^G with a simplified time-to-build based on lags T:

$$K_t^G = (1-\delta)K_{t-1}^G + \sum_{j=0}^{T} \theta_j G_{t-j}^I.$$

where the sum of weights θ_j is equal to one. In our baseline setup, we set weights at values such that time-to-buid is evenly distributed between 1 and 6 years. Despite the fixed aggregate stock, shares of the aggregate capital stock can be freely allocated across the f firms, implying that real marginal cost, $MC_t(f)/P_t$ is identical across firms and equal to

$$\frac{MC_t}{P_t} = \frac{W_t/P_t}{MPL_t} = \frac{W_t/P_t}{(1-\alpha)\, Z_t\, (K_t^{tot})^{\alpha}\, N_t{}^{-\alpha}}. \tag{A.7}$$

The second notable difference relative to the setup in the full model with capital is that here we do not allow for dynamic indexation to lagged inflation. Instead, all firms which are not allowed to reoptimize their prices in period t (which is the case with probability ξ_p), update their prices according to the following formula

$$\tilde{P}_t = (1+\pi)\, P_{t-1}, \tag{A.8}$$

where π is the steady-state (net) inflation rate and $\tilde{P}_t$ is the updated price.

Given Calvo-style pricing frictions, firm f that is allowed to reoptimize its price ($P_t^{opt}(f)$) solves the following problem

$$\max_{P_t^{opt}(f)} \mathrm{E}_t \sum_{j=0}^{\infty} \xi_p^j \psi_{t,t+j} \left[(1+\pi)^j\, P_t^{opt}(f) - MC_{t+j} \right] Y_{t+j}(f) \tag{A.9}$$

where $\psi_{t,t+j}$ is the stochastic discount factor (the conditional value of future profits in utility units, i.e. $\beta^j \mathrm{E}_t \frac{\lambda_{t+j}}{\lambda_t}$, recalling that the household is the owner of the firms), θ_p the net markup, and the demand for firm f is given by

$$\begin{aligned} \frac{Y_t(f)}{Y_t} &= \frac{1+\theta_p}{1+\theta_p-\theta_p\epsilon_p} \left(\left[\frac{P_t^*(f)}{P_t \Lambda_t^p} \right]^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} - \frac{\theta_p\epsilon_p}{1+\theta_p} \right), \\ \Lambda_t^p &= 1 - \frac{\theta_p\epsilon_p}{1+\theta_p} + \frac{\theta_p\epsilon_p}{1+\theta_p} \int \frac{P_t(f)}{P_t} df. \end{aligned} \tag{A.10}$$

A.1.3. Government

The evolution of nominal government debt is determined by the following equation

$$B_{G,t} = (1+i_{t-1})\, B_{G,t-1} + P_t G_t - \tau_{C,t} P_t C_t - \tau_{N,t} W_t N_t - T_t - MB_{t+1} + MB_t \tag{A.11}$$

where $G_t = G_t^C + G_t^I$ denotes real government expenditure (consumption and investment) on the final good Y_t. Scaling with $1/(P_t Y)$, we obtain

$$\frac{B_{G,t}}{P_t Y} = \frac{(1+i_{t-1})}{(1+\pi_t)} \frac{B_{G,t-1}}{P_{t-1} Y} + \frac{G_t}{Y} - \tau_{C,t} \frac{C_t}{Y} - \tau_{N,t} \frac{W_t N_t}{P_t Y} - \frac{T_t}{P_t Y} - \frac{MB_{t+1}}{P_t Y} + \frac{MB_t}{P_t Y}. \tag{A.12}$$

The government adjust the labor-income tax rate to stabilize dynamics of government debt (as a share of nominal trend GDP, $b_{G,t} \equiv \frac{B_{G,t}}{P_t Y}$) according to the rule (13).

Turning to the central bank, it is assumed to adhere to the non-linear Taylor-type policy rule (in log-linearized form) in equation (3), where i denotes the steady-state (net) nominal interest rate, which is given by $r + \pi$ where $r \equiv 1/\beta - 1$.

A.1.4. The Aggregate Resource Constraint

We now turn to discuss the derivation of the aggregate resource constraint. Let Y_t^* denote the unweighted average (sum) of output for each firm f, i.e.

$$Y_t^* = \int_0^1 Y_t(f) df$$

Recalling that $\frac{Y_t(f)}{Y_t} = \frac{1+\theta_p}{1+\theta_p-\theta_p\epsilon_p} \left(\left[\frac{P_t^*(f)}{P_t \Lambda_t^p} \right]^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} - \frac{\theta_p\epsilon_p}{1+\theta_p} \right)_t$, it follows that

$$\begin{aligned} Y_t^* &= \int_0^1 Y_t(f) df = \int_0^1 \frac{1+\theta_p}{1+\theta_p-\theta_p\epsilon_p} \left(\left[\frac{P_t(f)}{P_t \Lambda_t^p} \right]^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} - \frac{\theta_p\epsilon_p}{1+\theta_p} \right) Y_t df \\ &= \left(\frac{1}{P_t} \right)^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} \int_0^1 \frac{1+\theta_p}{1+\theta_p-\theta_p\epsilon_p} \left(\left[\frac{P_t(f)}{\Lambda_t^p} \right]^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} - \frac{\theta_p\epsilon_p}{1+\theta_p} \right) df Y_t \\ &= \left(\frac{P_t^*}{P_t} \right)^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} Y_t, \end{aligned}$$

where Y_t is aggregate output of the final goods sector, as defined above, and P_t^* is the indicated weighted average of individual prices, defined as

$$P_t^* \equiv \left(\int_0^1 \frac{1+\theta_p}{1+\theta_p-\theta_p\epsilon_p} \left(\left[\frac{P_t(f)}{\Lambda_t^p} \right]^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} - \frac{\theta_p\epsilon_p}{1+\theta_p} \right) df \right)^{-\frac{\theta_p}{1+\theta_p-\theta_p\epsilon_p}}. \tag{A.13}$$

Notice how the weights for P_t^* differ from what they are for the aggregate price level P_t (see eq. B.2). Now, actual output is Y_t, and this is what is available to be divided into private consumption and government spending:

$$Y_t = C_t + G_t. \tag{A.14}$$

Using the definition of the production function (A.5), we can write the resource constraint in real terms as follows:

$$\underbrace{C_t + G_t}_{\equiv Y_t} \leq \left(\frac{P_t^*}{P_t}\right)^{\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} \underbrace{Z_t \left(K_t^{tot}\right)^{\alpha} N_t{}^{1-\alpha}}_{\equiv Y_t^*}. \tag{A.15}$$

The sticky price distortion clearly introduces a wedge between input use and the output available for consumption (including by the government). However, this term vanishes in the log-linearized version of the model.

A.1.5. Equilibrium

We now collect the equilibrium relationships in the model and derive a log-linear approximation of the model.

Collecting the equations First, we may regard the households' equations (A.3) and (A.4) as determining C_t and N_t, and marginal cost relation equation (A.7) as determining MC_t/P_t, and the aggregate resource constraint (A.15) as determining the real wage W_t/P_t. The Taylor-type policy rule determines the nominal interest rate i_t, and the firms' pricing equations (A.10) and (A.13) determine the evolution of the aggregate price level P_t, whereas the (shadow) gross real interest rate $1 + r_t$ is determined by the Fisher relationship

$$1 + r_t = \mathrm{E}_t \frac{(1 + i_t)}{(1 + \pi_{t+1})} \tag{A.16}$$

Finally, the fiscal budget constraint (A.12) determines the evolution of government debt $B_{G,t}$, and the final goods resource constraint (A.14) relates consumption and government spending to final output Y_t. The other fiscal variables, $G_t, \tau_{C,t}, \tau_{N,t}$ and τ_t, are exogenous or determined by policy rules.

Log-linear Approximation of Model We will now derive the equations in Section 2 in turn. We start with the sticky price equilibrium conditions, and then discuss the flex-price equilibrium. In general, a log-linearized variable is denoted with lower case letters, and derived as

$$x_t = \frac{dX_t}{X}, \tag{A.17}$$

except in the special case $X = 0$ when the log-linearized variable is simply given by dX_t (e.g. government debt as a share of nominal trend GDP, and the lump-sum tax rate). Moreover, for inflation and interest rates, we use the approximation that $d(1 + x_t) \approx x_t$ because x_t is small.

Finally, note that for distortionary tax rates, we use $d\tau_{X,t} \equiv \tau_{X,t}$ (thus, rather than introducing new notation, the tax rates are hereafter understood to be in deviations from their steady state level; this is also the case for the preference shock ν_t).

Totally differentiating the government debt evolution equation (A.12), we obtain (dropping the seignorage term which is assumed to be arbitrarily small)

$$b_{G,t} = (1+r)\, b_{G,t-1} + g_y g_t - c_y \left(\tau_{C,t} + \tau_C c_t\right) - \frac{1-\alpha}{1+\theta_p}\left(\tau_{N,t} + \tau_N \zeta_t + \tau_N n_t\right) - \tau_t + b_G (1+r)(i_{t-1} - \pi_t), \tag{A.18}$$

where we have introduced the notation that ζ_t represents the real wage (as percent deviation from steady state, i.e. $d(W_t/P_t)/\left(W/P\right)$), defined $g_y \equiv G/Y$ and $c_y \equiv 1 - g_y$, and used that $\frac{WN}{PY} = \frac{1-\alpha}{1+\theta_p} \equiv s_N$ and our simplifying assumption that $b_G = 0$. Assuming that the labor income tax is the only tax which balances the budget in steady state and denoting $\tau \equiv \frac{T}{PY}$ the steady-state share of lump-sum taxes, it then follows that:

$$\tau_N = \frac{1+\theta_p}{1-\alpha}\left(g_y - \tau_C(1-g_y) - \tau\right). \tag{A.19}$$

To derive a log-linearized representation for real marginal cost, we work from the equation (A.7), which implies

$$mc_t = \zeta_t - y_t + n_t = \zeta_t + \frac{\alpha}{1-\alpha}\left(y_t - z_t/\alpha - (1-\vartheta)k_t^G\right),$$

where the second equality follows from (A.5). By noting that real marginal cost is constant in the flex-price equilibrium, we have

$$\zeta_t^{pot} - y_t^{pot} + n_t^{pot} = \zeta_t^{pot} + \frac{\alpha}{1-\alpha}\left(y_t^{pot} - z_t/\alpha - (1-\vartheta)k_t^G\right) = 0. \tag{A.20}$$

Accordingly, we can write (log-linearized) real marginal cost as

$$mc_t = \left(\zeta_t - \zeta_t^{pot}\right) + \frac{\alpha}{1-\alpha}\left(y_t - y_t^{pot}\right). \tag{A.21}$$

In order to write this equation solely in terms of the output gap,

$$x_t \equiv y_t - y_t^{pot}, \tag{A.22}$$

we need to derive a log-linearized equation for the real wage. To obtain such a measure, we log-linearize equation (A.4) to obtain

$$\chi n_t + \frac{1}{\sigma(1-\nu)}\left(c_t - \nu \nu_t\right) = \zeta_t - \frac{\tau_{N,t}}{1-\tau_N} - \frac{\tau_{C,t}}{1+\tau_C},$$

again recalling that $\tau_{j,t}$ for $j = [N, C]$ and ν_t are to be interpreted as percentage point deviations. By log-linearizing and substituting the aggregate resource constraint in (A.14) into this expression, we obtain

$$\zeta_t = \chi n_t + \frac{1}{\sigma(1-\nu)} \left(\frac{1}{1-g_y} (y_t - g_y g_t) - \nu \nu_t \right) + \frac{\tau_{N,t}}{1-\tau_N} + \frac{\tau_{C,t}}{1+\tau_C},$$

and using (A.5) , i.e. that $n_t = \frac{1}{1-\alpha} \left(y_t - z_t - \alpha(1-\vartheta) k_t^G \right)$, we finally derive the following expression for the log-linearized real wage:

$$\zeta_t = \left(\frac{\chi}{1-\alpha} + \frac{1}{\sigma(1-\nu)(1-g_y)} \right) y_t - \frac{\chi}{1-\alpha} \left(z_t + \alpha(1-\vartheta) k_t^G \right) - \frac{g_y}{\sigma(1-\nu)(1-g_y)} g_t - \frac{\nu}{\sigma(1-\nu)} \nu_t + \frac{1}{1-\tau_N} \tau_{N,t} + \frac{}{1} \tag{A.23}$$

Next, we log-linearize the consumption Euler equation, (A.3), to get

$$-\frac{c_t - \nu v_t}{\sigma(1-\nu)} = \mathrm{E}_t \left[i_t - \pi_{t+1} - \frac{1}{1+\tau_c} \Delta \tau_{C,t+1} - \frac{c_{t+1} - \nu \nu_{t+1}}{\sigma(1-\nu)} \right],$$

where we have used that

$$1 = \beta \frac{1+i}{1+\pi} = \beta (1+r).$$

By substituting the log-linearized aggregate resource constraint (A.14) into this expression, and defining:

$$\hat{\sigma} \equiv \sigma(1-\nu)(1-g_y). \tag{A.24}$$

we obtain after some rearranging:

$$y_t = \mathrm{E}_t y_{t+1} - \hat{\sigma}(i_t - \mathrm{E}_t \pi_{t+1}) - g_y \mathrm{E}_t \Delta g_{t+1} - (1-g_y) \nu \mathrm{E}_t \Delta \nu_{t+1} + \frac{\hat{\sigma}}{1+\tau_c} \mathrm{E}_t \Delta \tau_{C,t+1}, \tag{A.25}$$

which is the log-linearized IS curve equation. Using the labor supply equation (A.23) and labor demand equation (A.20) under flexible prices, we get

$$\left(\frac{\chi}{1-\alpha} + \frac{1}{\hat{\sigma}} + \frac{\alpha}{1-\alpha} \right) y_t^{pot} = \left[\frac{g_y}{\hat{\sigma}} g_t + \frac{\nu}{\sigma(1-\nu)} \nu_t - \frac{1}{1-\tau_N} \tau_{N,t}^{pot} - \frac{1}{1+\tau_C} \tau_{C,t} + \frac{1+\chi}{1-\alpha} \left(z_t + \alpha(1-\vartheta) k_t^G \right) \right],$$

where we use the notation z_t^{pot} for endogenous variables, and simply z_t for exogenous variables. Note that $\tau_{N,t}^{pot}$ is treated for the moment as an endogenous variable as it potentially depends on other endogenous variables via (13). Using the notation

$$\phi_{mc} \equiv \frac{\chi}{1-\alpha} + \frac{1}{\hat{\sigma}} + \frac{\alpha}{1-\alpha}, \tag{A.26}$$

the solution for potential output can be written

$$y_t^{pot} = \frac{1}{\phi_{mc} \hat{\sigma}} \left[g_y g_t + (1-g_y) \nu \nu_t - \frac{\hat{\sigma}}{1-\tau_N} \tau_{N,t}^{pot} - \frac{\hat{\sigma}}{1+\tau_C} \tau_{C,t} + \hat{\sigma} \frac{1+\chi}{1-\alpha} \left(z_t + \alpha(1-\vartheta) k_t^G \right) \right]. \tag{A.27}$$

To get a tractable solution for the potential real interest rate, we use the definition in (A.24) to rearrange (A.25) as:

$$r_t^{pot} = \frac{1}{\hat{\sigma}} \mathrm{E}_t \Delta y_{t+1}^{pot} - \frac{g_y}{\hat{\sigma}} \mathrm{E}_t \Delta g_{t+1} - \frac{1-g_y}{\hat{\sigma}} \nu \mathrm{E}_t \Delta \nu_{t+1} + \frac{1}{1+\tau_c} \mathrm{E}_t \Delta \tau_{C,t+1},$$

and by substituting the expression for y_t^{pot} in (A.27) into this equation, we obtain

$$r_t^{pot} = \frac{1}{\hat{\sigma}\phi_{mc}} \mathrm{E}_t \begin{bmatrix} \frac{g_y}{\hat{\sigma}} \Delta g_{t+1} + \frac{1-g_y}{\hat{\sigma}} \nu \Delta \nu_{t+1} \\ -\frac{1}{1-\tau_N} \Delta \tau_{N,t+1}^{pot} - \frac{1}{1+\tau_C} \Delta \tau_{C,t+1} \\ +\frac{1+\chi}{1-\alpha} \left(\Delta z_{t+1} + \alpha (1-\vartheta) \Delta k_{t+1}^G \right) \end{bmatrix} - \frac{g_y}{\hat{\sigma}} \mathrm{E}_t \Delta g_{t+1} - \frac{1-g_y}{\hat{\sigma}} \nu \mathrm{E}_t \Delta \nu_{t+1} + \frac{1}{1+\tau_c} \mathrm{E}_t \Delta \tau_{C,t+1},$$

which can be rearranged as

$$r_t^{pot} = \tfrac{1}{\hat{\sigma}} \left(1 - \tfrac{1}{\hat{\sigma}\phi_{mc}}\right) \mathrm{E}_t \left[-g_y \Delta g_{t+1} - (1-g_y) \nu \Delta \nu_{t+1} \right] - \tfrac{1}{\hat{\sigma}\phi_{mc}(1-\tau_N)} \mathrm{E}_t \Delta \tau_{N,t+1}^{pot} + \left(1 - \tfrac{1}{\hat{\sigma}\phi_{mc}}\right) \tfrac{1}{1+\tau_c} \mathrm{E}_t \Delta \tau_{C,t+1} + \frac{1}{\hat{\sigma}\phi_{mc}} \frac{1}{1} \tag{A.28}$$

which is the general solution for the potential real interest rate.

From the equations above, it is an easy task to obtain the equations stated in the main text for the stylized model. Accordingly, equation (5) follows from (A.28), and (4) follows from (A.27). The IS-curve (1) obtains from (A.25) which holds for actual and potential output, so that:

$$\begin{aligned} y_t - y_t^{pot} = & \left(\mathrm{E}_t y_{t+1} - \hat{\sigma} \left(i_t - \mathrm{E}_t \pi_{t+1} \right) - g_y \mathrm{E}_t \Delta g_{t+1} - (1-g_y) \nu \mathrm{E}_t \Delta \nu_{t+1} + \tfrac{\hat{\sigma}}{1+\tau_c} \mathrm{E}_t \Delta \tau_{C,t+1} \right) \\ & - \left(\mathrm{E}_t y_{t+1}^{pot} - \hat{\sigma} r_t^{pot} - g_y \mathrm{E}_t \Delta g_{t+1} - (1-g_y) \nu \mathrm{E}_t \Delta \nu_{t+1} + \tfrac{\hat{\sigma}}{1+\tau_c} \mathrm{E}_t \Delta \tau_{C,t+1} \right), \end{aligned}$$

which can be written as equation (1) by using the definitions (A.22) and (A.24).

As is well known, log-linearization around the inflation target π of the first order condition of the problem (A.9) combined with equations (B.2) and (A.8) results in the following Phillips curve

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \frac{\left(1-\xi_p\right)\left(1-\beta\xi_p\right)}{\xi_p \left(1+\theta_p \epsilon_p\right)} mc_t. \tag{A.29}$$

To write the model in terms of the output gap x_t instead of mc_t as in the text, we use (A.21) and (A.23), which in the model when $\tau_{N,t}$ varies endogenously according to the rule (13) implies that a wedge between the actual and potential labor tax-rate will enter into marginal costs:

$$\begin{aligned} mc_t &= \left(\zeta_t - \zeta_t^{pot} \right) + \frac{\alpha}{1-\alpha} \left(y_t - y_t^{pot} \right) \qquad \text{(A.30)} \\ &= \left(\frac{\chi}{1-\alpha} + \frac{1}{\sigma(1-\nu)(1-g_y)} \right) \left(y_t - y_t^{pot} \right) + \frac{1}{1-\tau_N} \left(\tau_{N,t} - \tau_{N,t}^{pot} \right) + \frac{\alpha}{1-\alpha} \left(y_t - y_t^{pot} \right) \\ &= \phi_{mc} x_t + \frac{1}{1-\tau_N} \left(\tau_{N,t} - \tau_{N,t}^{pot} \right), \end{aligned}$$

where x_t is defined accordingly with (A.22) and ϕ_{mc} is defined as in (A.26). Using this in (A.29), we obtain (2) with κ_p defined as in (7). Equation (A.30) implies that a negative gap between the actual and potential labor income tax rate will put downward pressure on marginal costs and hence inflation.

The government debt accumulation equation (11) obtains from (A.18) by using $\zeta_t + n_t = y_t + \phi_{mc} x_t + \frac{1}{1-\tau_N}\left(\tau_{N,t} - \tau_{N,t}^{pot}\right)$ and assuming $b_G = 0$. Apart from the equations stated in the main text, we use (A.27) to compute y_t^{pot}, which enables us to compute actual output as $y_t = x_t + y_t^{pot}$. To get hours worked and real wages in (11), we use (A.23) and $n_t = \frac{1}{1-\alpha}\left(y_t - \alpha(1-\vartheta)k_t^G\right)$.

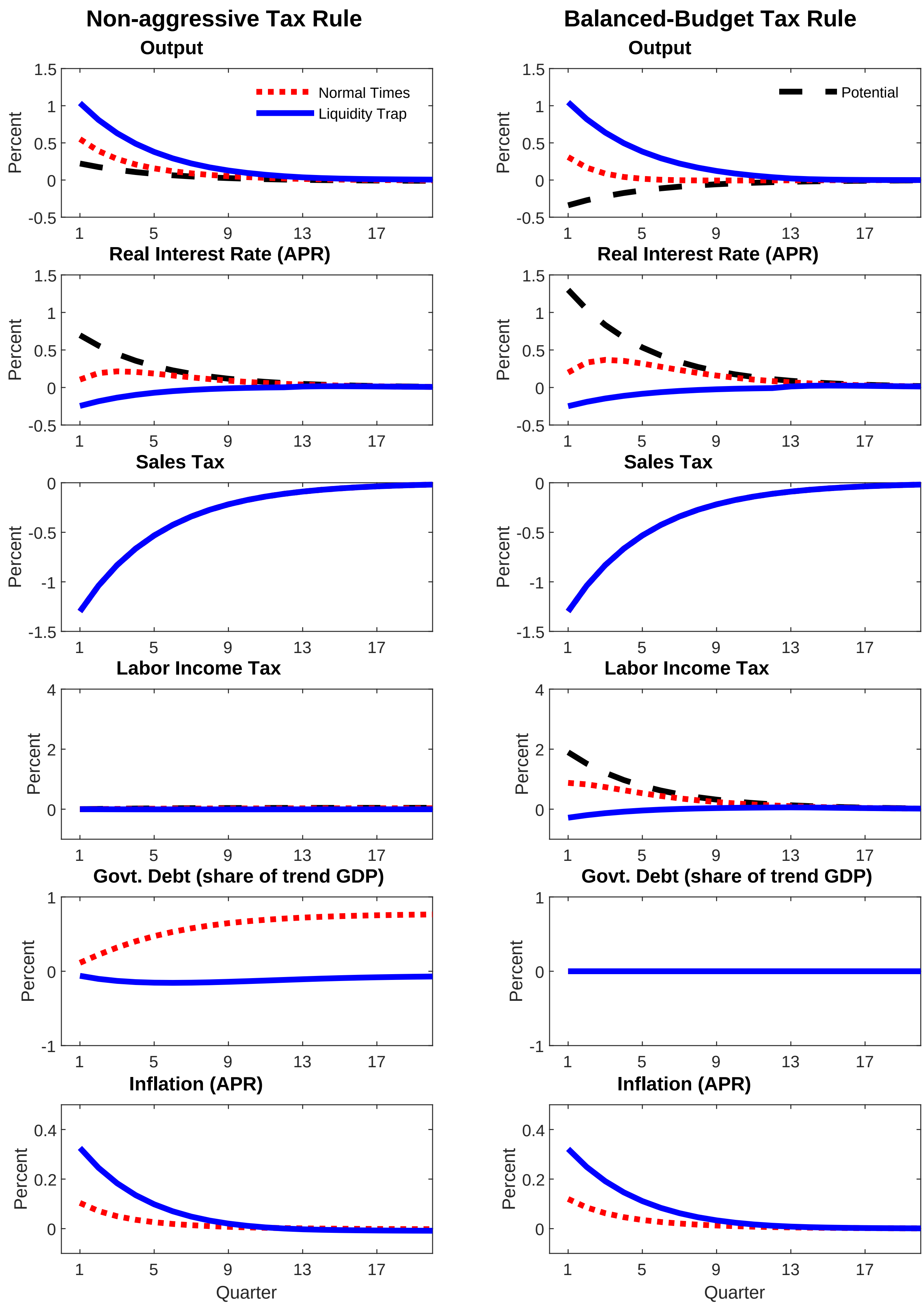
A.2. Robustness Results in Stylized Model

Below, we report and discuss briefly some additional results referred to in Section 3 of the main text.

A.2.1. Temporary Sales Tax Cut

In Figure A.1, we redo the experiment in Figure 2 where instead of a gradual sales tax hike we implement a temporary sales tax cut. In this case, we consider the same-sized changes in the sales tax, but assume an AR(1) process with persistence 0.8 (as opposed to the AR(2) process used for the results discussed in the main text). As can be seen from the figure, the output impulses are very similar to those reported in the baseline model, whereas the effects on potential output are significantly different under a balanced-budget rule. Even in a case without any near-term changes in other fiscal instrument (non-aggressive rule), we find that output is sufficiently high in a liquidity trap to make the tax cut self-financing.

Figure A.1: Temporary Sales Tax Cut in Normal Times and in a Liquidity Trap.



Appendix B. The New-Keynesian TANK Model

This appendix describes the model used in Section 4 and its calibration in more detail.

B.1. The Model

The model is essentially a variant of the CEE/SW model augmented with "Keynesian" households. As such, it incorporates nominal rigidities by assuming that labor and product markets exhibit monopolistic competition, and that wages and prices are determined by staggered nominal contracts of random duration (following Calvo (1983) and Yun (1996)). In addition, the model includes an array of real rigidities, including habit persistence in consumption, and costs of changing the rate of investment. Monetary policy follows a Taylor rule, and fiscal policy specifies that spending is financed by taxes to stabilize government debt.

B.1.1. Firms and Price-Setting

Final Goods Production We assume that a single final output good Y_t is produced using a continuum of differentiated intermediate goods $Y_t(f)$. The technology for transforming these intermediate goods into the final output good is constant returns to scale, and is of the Kimball form:

$$\int_0^1 G_Y\left(\frac{Y_t(f)}{Y_t}\right) df = 1 \tag{B.1}$$

where

$$G_Y\left(\frac{Y_t(f)}{Y_t}\right) = \frac{1+\theta_p}{1-\theta_p\epsilon_p}\left[\left(\frac{1+\theta_p-\theta_p\epsilon_p}{1+\theta_p}\right)\frac{Y_t(f)}{Y_t} + \frac{\theta_p\epsilon_p}{1+\theta_p}\right]^{\frac{1-\theta_p\epsilon_p}{1+\theta_p-\theta_p\epsilon_p}} + \left[1 - \frac{1+\theta_p}{1-\theta_p\epsilon_p}\right]$$

and $\theta_p > 0$ and $\epsilon_p > 0$.

Firms that produce the final output good are perfectly competitive in both product and factor markets. Thus, final goods producers minimize the cost of producing a given quantity of the output index Y_t, taking as given the price $P_t(f)$ of each intermediate good $Y_t(f)$. Moreover, final goods producers sell units of the final output good at a price P_t that can be interpreted as the aggregate price index:

$$P_t\Lambda_t^p = \left[\int_0^1 P_t(f)^{-\frac{1-\theta_p\epsilon_p}{\theta_p}} df\right]^{-\frac{\theta_p}{1-\theta_p\epsilon_p}} \tag{B.2}$$

where

$$\Lambda_t^p = 1 - \frac{\theta_p\epsilon_p}{1+\theta_p} + \frac{\theta_p\epsilon_p}{1+\theta_p}\int \frac{P_t(f)}{P_t} df.$$

Intermediate Goods Production A continuum of intermediate goods $Y_t(f)$ for $f \in [0,1]$ is produced by monopolistically competitive firms, each of which produces a single differentiated good.

Each intermediate goods producer faces a demand function for its output good that varies inversely with its output price $P_t(f)$, and directly with aggregate demand Y_t:

$$\frac{Y_t(f)}{Y_t} = \frac{1+\theta_p}{1+\theta_p-\theta_p\epsilon_p}\left(\left[\frac{P_t^*(f)}{P_t\Lambda_t^p}\right]^{-\frac{1+\theta_p-\theta_p\epsilon_p}{\theta_p}} - \frac{\theta_p\epsilon_p}{1+\theta_p}\right) \tag{B.3}$$

Each intermediate goods producer utilizes capital services $K_t^{tot}(f)$ and a labor index $L_t(f)$ (defined below) to produce its respective output good. The form of the production function is Cobb-Douglas:

$$Y_t(f) = Z_t K_t^{tot}(f)^{\alpha} L_t(f)^{1-\alpha}, \tag{B.4}$$

$$K_t^{tot}(f) = \left(K_t^P(f)\right)^{\vartheta}\left(K_t^G\right)^{1-\vartheta}. \tag{B.5}$$

Firms face perfectly competitive factor markets for hiring capital and the labor index. Thus, each firm chooses $K_t(f)$ and $L_t(f)$, taking as given both the rental price of capital R_{Kt} and the aggregate wage index W_t (defined below). The accumulation of government capital K_t^G is defined using a simplified time-to-build as in the stylized model. Firms can costlessly adjust either factor of production. Thus, the standard static first-order conditions for cost minimization imply that all firms have identical marginal cost per unit of output.

The prices of the intermediate goods are determined by Calvo-Yun style staggered nominal contracts. In each period, each firm f faces a constant probability, $1-\xi_p$, of being able to reoptimize its price $P_t(f)$. The probability that any firm receives a signal to reset its price is assumed to be independent of the time that it last reset its price. If a firm is not allowed to optimize its price in a given period, we follow Christiano, Eichenbaum and Evans (2005) in assuming that it adjusts its price by a weighted combination of the lagged and steady state rate of inflation, i.e., $P_t(f) = \pi_{t-1}^{\iota_p}\pi^{1-\iota_p}P_{t-1}(f)$ where $0 \le \iota_p \le 1$. A positive value of ι_p introduces structural inertia into the inflation process.

B.1.2. Households and Wage Setting

We assume a continuum of monopolistically competitive households (indexed on the unit interval), each of which supplies a differentiated labor service to the production sector; that is, goods-producing firms regard each household's labor services, $N_t(h)$, $h \in [0,1]$, as an imperfect substitute for the labor services of other households. It is convenient to assume that a representative labor aggregator combines households' hours of labor in the same proportions as firms would choose.

Thus, the aggregator's demand for each household's labor is equal to the sum of firms' demands. The labor index L_t has the Dixit-Stiglitz form:

$$\int_0^1 G_L\left(\tfrac{N_t(h)}{L_t}\right) dh = 1 \tag{B.6}$$

where

$$G_L\left(\tfrac{N_t(h)}{L_t}\right) = \tfrac{1+\theta_w}{1-\theta_w\epsilon_w}\left[\left(\tfrac{1+\theta_w-\theta_w\epsilon_w}{1+\theta_w}\right)\tfrac{N_t(h)}{L_t} + \tfrac{\theta_w\epsilon_w}{1+\theta_w}\right]^{\frac{1-\theta_w\epsilon_w}{1+\theta_w-\theta_w\epsilon_w}} + \left[1 - \tfrac{1+\theta_w}{1-\theta_w\epsilon_w}\right]$$

and $\theta_w > 0$. The aggregator minimizes the cost of producing a given amount of the aggregate labor index, taking each household's wage rate $W_t(h)$ as given, and then sells units of the labor index to the production sector at their unit cost W_t:

$$W_t\Lambda_t^w = \left[\int_0^1 W_t(h)^{-\frac{1-\theta_w\epsilon_w}{\theta_w}} dh\right]^{-\frac{\theta_w}{1-\theta_w\epsilon_w}} \tag{B.7}$$

where

$$\Lambda_t^w = 1 - \frac{\theta_w\epsilon_w}{1+\theta_w} + \frac{\theta_w\epsilon_w}{1+\theta_w}\int \frac{W_t(h)}{W_t} dh.$$

It is natural to interpret W_t as the aggregate wage index. The aggregator's demand for the labor hours of household h – or equivalently, the total demand for this household's labor by all goods-producing firms – is given by

$$\frac{N_t(h)}{L_t} = \frac{1+\theta_w}{1+\theta_w-\theta_w\epsilon_w}\left(\left[\frac{W_t^*(h)}{W_t\Lambda_t^w}\right]^{-\frac{1+\theta_w-\theta_w\epsilon_w}{\theta_w}} - \frac{\theta_w\epsilon_w}{1+\theta_w}\right) \tag{B.8}$$

The utility functional of a typical member of household h is

$$\mathbb{E}_t\sum_{j=0}^{\infty}\beta^j\{\frac{1}{1-\sigma}C_{t+j}(h) - \varkappa C_{t+j-1} - \nu_c\nu_t\}^{1-\sigma} - \frac{\chi_0}{1+\chi}N_{t+j}(h)^{1+\chi}\} \tag{B.9}$$

where the discount factor β satisfies $0 < \beta < 1$. The period utility function depends on household h's current consumption $C_t(h)$, as well as on lagged aggregate per capita consumption to allow for the possibility of external habit persistence (Smets and Wouters 2003). As in the simple model considered in the previous section, a positive taste shock ν_t raises the marginal utility of consumption associated with any given consumption level. The period utility function also depends inversely on hours worked $N_t(h)$.

Household h's budget constraint in period t states that its expenditure on goods and net purchases of financial assets must equal its disposable income:

$$
\begin{aligned}
& P_t C_t(h) + P_t I_t(h) + \frac{1}{2}\psi_I P_t \frac{\left(I_t(h) - I_{t-1}(h)\right)^2}{I_{t-1}(h)} + \\
& P_{B,t} B_{G,t+1} - B_{G,t} + \int_s \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h) \qquad \text{(B.10)} \\
= \; & (1-\tau_{N,t}) W_t(h) N_t(h) + (1-\tau_K) R_{K,t} K_t(h) + \delta\tau_K P_t K_t(h) + \Gamma_t(h) - T_t(h)
\end{aligned}
$$

Thus, the household purchases the final output good (at a price of P_t), which it chooses either to consume $C_t(h)$ or invest $I_t(h)$ in physical capital. The total cost of investment to each household h is assumed to depend on how rapidly the household changes its rate of investment (as well as on the purchase price). Our specification of investment adjustment costs as depending on the square of the change in the household's gross investment rate follows Christiano, Eichenbaum, and Evans (2005). Investment in physical capital augments the household's (end-of-period) capital stock $K_{t+1}(h)$ according to a linear transition law of the form:

$$
K_{t+1}(h) = (1-\delta) K_t(h) + I_t(h) \qquad \text{(B.11)}
$$

In addition to accumulating physical capital, households may augment their financial assets through increasing their government bond holdings ($P_{B,t} B_{G,t+1} - B_{G,t}$), and through the net acquisition of state-contingent bonds. We assume that agents can engage in frictionless trading of a complete set of contingent claims. The term $\int_s \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h)$ represents net purchases of state-contingent domestic bonds, with $\xi_{t,t+1}$ denoting the state price, and $B_{D,t+1}(h)$ the quantity of such claims purchased at time t. Each member of household h earns after-tax labor income $(1-\tau_{N,t}) W_t(h) N_t(h)$, after-tax capital rental income of $(1-\tau_K) R_{K,t} K_t(h)$, and a depreciation allowance of $\delta\tau_K P_t K_t(h)$. Each member also receives an aliquot share $\Gamma_t(h)$ of the profits of all firms, and pays a lump-sum tax of $T_t(h)$ (this may be regarded as taxes net of any transfers).

In each period t, each member of household h maximizes the utility functional (B.9) with respect to its consumption, investment, (end-of-period) capital stock, bond holdings, and holdings of contingent claims, subject to its labor demand function (B.8), budget constraint (B.10), and transition equation for capital (B.11). Households also set nominal wages in Calvo-style staggered contracts that are generally similar to the price contracts described above. Thus, the probability that a household receives a signal to reoptimize its wage contract in a given period is denoted by $1-\xi_w$. In addition, we specify a dynamic indexation scheme for the adjustment of the wages of those households that do not get a signal to reoptimize, i.e., $W_t(h) = \omega_{t-1}^{\iota_w} \pi^{1-\iota_w} W_{t-1}(h)$, where

ω_{t-1} is gross nominal wage inflation in period $t-1$. Dynamic indexation of this form introduces some structural persistence into the wage-setting process.

B.1.3. Fiscal and Monetary Policy and the Aggregate Resource Constraint

Government purchases G_t are assumed to follow an exogenous AR(1) process with a persistence coefficient of 0.9. Government purchases have no effect on the marginal utility of private consumption, nor do they serve as an input into goods production. Government expenditure is financed by a combination of labor, capital, and lump-sum taxes. The government does not need to balance its budget in each period, and issues nominal debt to finance budget deficits according to:

$$P_{B,t}B_{G,t+1} - B_{G,t} = P_tG_t - T_t - \tau_{C,t}P_tC_t - \tau_{N,t}W_tL_t - \tau_{K,t}\left(R_{K,t} - \delta P_t\right)K_t. \tag{B.12}$$

In eq. (B.12), all quantity variables are aggregated across households, so that $B_{G,t}$ is the aggregate stock of government bonds and K_t is the aggregate capital stock, and $T_t = (\int_0^1 T_t(h)\, dh)$ aggregate lump-sum taxes. In our benchmark specification, the lump-sum and capital tax rate is held fixed, and labor income taxes adjust endogenously according to a tax rate reaction function that allows taxes to respond to debt subject to smoothing. In log-linearized form:

$$\tau_{N,t} - \tau_N = \varphi_\tau\left(\tau_{N,t-1} - \tau_N\right) + \left(1-\varphi_\tau\right)\varphi_b\left(\tilde{b}_{G,t} - \tilde{b}_G\right), \tag{B.13}$$

where $\tilde{b}_{G,t} \equiv \frac{B_{G,t}}{4P_tY}$. As the difference between lump-sum and distortionary tax financing can potentially be substantial in long-lasting liquidity traps, we choose to work with distortionary tax financing − which we think is more empirically plausible − in this paper.

Monetary policy is assumed to be given by a Taylor-style interest rate reaction function similar to equation (3) except allowing for a smoothing coefficient γ_i:

$$i_t = \left\{\max\left(-i, \left(1-\gamma_i\right)\left(\gamma_\pi \pi_t + \gamma_x x_t\right) + \gamma_i i_{t-1}\right)\right\} \tag{B.14}$$

Finally, total output of the service sector is subject to the resource constraint:

$$Y_t = C_t + I_t + G_t + \psi_{I,t} \tag{B.15}$$

where $\psi_{I,t}$ is the adjustment cost on investment aggregated across all households (from eq. B.10, $\psi_{I,t} \equiv \frac{1}{2}\psi_I \frac{(I_t(h)-I_{t-1}(h))^2}{I_{t-1}(h)}$).

B.1.4. Keynesian Households

In the full model with non-Ricardian households, we assume that a proportion s_{kh} of the population consists of "Keynesian" households whose members consume their current after-tax income each period, and set their wage equal to the average wage of the optimizing households. Because all households face the same labor demand schedule, each Keynesian household works the same number of hours as the average optimizing household. Thus, the consumption of Keynesian households $C_t^K(h)$ is simply determined as

$$P_t C_t^K(h) = (1 - \tau_{Nt}) W_t(h) N_t(h) - T_t, \tag{B.16}$$

where T_t denotes (net) lump-sum taxes. The consumption of non-Keynesian households is given the consumption Euler equation derived by maximizing (B.9) subject to (B.10).

B.1.5. Solution and Calibration

To analyze the model's behavior, we log-linearize the model's equations around the non-stochastic steady state. Nominal variables, such as the contract price and wage, are rendered stationary by suitable transformations. To solve the unconstrained version of the model, we compute the reduced-form solution of the model for a given set of parameters using the numerical algorithm of Anderson and Moore (1985), which provides an efficient implementation of the solution method proposed by Blanchard and Kahn (1980).

When we solve the model subject to the non-linear monetary policy rule (B.14), we use the techniques described in Hebden, Lindé and Svensson (2009). An important feature of the Hebden, Lindé and Svensson algorithm is that the duration of the liquidity trap is endogenous and is affected by the size of the fiscal impetus. Their algorithm consists in adding a sequence of current and future innovations to the linear component of the policy rule to guarantee that the zero bound constraint is satisfied given the economy's state vector. The sequence of innovations is assumed to be correctly anticipated by private agents at each date. This solution method is easy to use and well suited to examining the implications of the zero bound constraint in models with large dimensional state spaces; moreover, it yields identical results to the method of Jung, Terinishi, and Watanabe (2005).

As in Section 2, we set the discount factor $\beta = 0.995$, and steady state (net) inflation $\pi = .005$, implying a steady state nominal interest rate of $i = .01$ at a quarterly rate. The subutility function over consumption is logarithmic, so that $\sigma = 1$, and the parameter determining the degree of habit persistence in consumption $\varkappa$ is set at 0.6 (similar to the empirical estimate of Smets and Wouters

2003). The Frisch elasticity of labor supply $\frac{1}{\chi}$ of 0.4 is well within the range of most estimates from the empirical labor supply literature (see e.g. Domeij and Flodén, 2006).

The shares of private and public capital stocks, $\vartheta\alpha$ and $(1-\vartheta)\alpha$, are respectively set to 0.25 and 0.05, by setting $\alpha = 0.3$ and $\vartheta = 0.83$. The quarterly depreciation rate of the capital stock $\delta = 0.02$, implying an annual depreciation rate of 8 percent. We set the cost of adjusting investment parameter $\psi_I = 3$, which is somewhat smaller than the value estimated by Christiano, Eichenbaum, and Evans (2005) using a limited information approach; however, the analysis of Erceg, Guerrieri, and Gust (2006) suggests that a lower value may be better able to capture the unconditional volatility of investment.

We maintain the assumption of a flat Phillips curve by setting the price contract duration parameter $\xi_p = 0.89$ and the Kimball curvature parameter $\epsilon_p = 10$. As in Christiano, Eichenbaum and Evans (2005), we also allow for a fair amount of intrinsic persistence by setting the price indexation parameter $\iota_p = 1$. It is worth emphasizing that our choice of ξ_p does not necessarily imply an average price contract duration of 9 quarters. Woodford (2003) and Altig et al. (2011) show in models very similar to ours that a low slope of the Phillips curve can be consistent with frequent price reoptimization if capital or labor is firm-specific, at least provided that the steady-state markup is not too high, and it is costly to vary capital utilization; both of these conditions are satisfied in our model, as the steady state markup is 20 percent ($\theta_p = .20$) and capital utilization is fixed. Specifically, our choice of ξ_p implies a Phillips curve slope of about 0.005. Given strategic complementarities in wage-setting across households, the wage markup influences the slope of the wage Phillips curve. Our choices of a wage markup of $\theta_W = 1/3$ and a wage contract duration parameter of $\xi_w = 0.818-$ along with a wage indexation parameter of $\iota_w = 1$ – imply that wage inflation is about twice as responsive to the wage markup as price inflation is to the price markup.

The parameters of the monetary policy rule are set as $\gamma_i = 0.7$, $\gamma_\pi = 2.5$ and $\gamma_x = 0.25$. These parameter choices are supported by simple regression analysis using instrumental variables over the 1993:Q1-2008:Q4 period. This analysis suggests that the response of the policy rate to inflation and the output gap has increased in recent years, which helps account for somewhat higher response coefficients than typically estimated when using sample periods which include the 1970s and 1980s. Overall, as noted in the main text, our calibration of the monetary policy rule and the Phillips Curve slope parameters tilts in the direction of reducing the sensitivity of inflation to macroeconomic shocks.

We set the population share of Keynesian households to optimizing households, s_{kh}, to 0.47, which implies that the Keynesian households' share of total consumption is about 1/4. This calibration perhaps overstates the role of non-Ricardian households in affecting consumption behavior, but seems useful to help put plausible bounds on how the multiplier may vary with the degree of non-Ricardian behavior in consumption (recognizing that the CEE/SW workhorse model is a special case in which $s_{kh} = 0$ and there are no financial frictions).

The share of government spending in total expenditure is set equal to 23 percent of GDP, split into 20pp of consumption and 3pp of investment. The government debt-to-GDP ratio is 1, close to the total estimated US federal government debt-to-output ratio before the coronavirus crisis. The steady state capital income tax rate, τ_K, is set to 0.25, while the lump-sum tax revenue-to-GDP ratio is set to -0.06. Given the depreciation rate $\delta = 0.02$, we set the depreciation allowance $\delta\tau_K = 0.005$. Given these choices, the government's intertemporal budget constraint implies that the labor income tax rate τ_N equals 0.356 in steady state. As noted in the main text, in one formulation the parameters in the fiscal policy rule (eq. 20) are set to imply a balanced budget. When we use a more empirically oriented gradual tax rule in equation (B.13) as in Traum and Yang (2011), we set $\varphi_\tau = 0.985$ and $\varphi_b = 0.1$. Importantly, given the low share of government revenue accounted for by lump-sum taxes, most of the variation in the government budget deficit reflects fluctuations in revenue from capital and labor income tax (due to variations in the tax base), and the service cost of debt.

B.2. Robustness Results in TANK Model

In this section we reports some robustness results in the TANK model.

B.2.1. Capital Income Tax Rule

In Figure B.1, we look at the sensitivity of our baseline results to the choice of fiscal instrument used to stabilize debt. More specifically, we assess the impact of the same gradual increase in the sales tax as in Figure 5 when the government use a balanced-budget *capital income* tax rule to fully stabilise government debt. We do not report the results in the case with a non-aggressive rule, as the effects in this case would be similar to those reported and already discussed for the non-aggressive labor income tax rule in Figure 5.

As is well known since Chamley (1985) and Judd (1986), the capital income tax creates greater distortions than the labor income or consumption sales tax and in a basic RBC framework this implies that the optimal capital tax is zero. Because of this feature, capital income tax cuts are generally associated with stronger multipliers than other tax cuts (see for example Clerc et al., 2017). Our workhorse model also has this feature and we find a strong amplification of the expansionary effects. However, one downside with a permanently higher sales tax financed by a reduction in capital income tax is that it may increase inequality between poor (hand-to-mouth) and rich (optimizing) households who own the capital stock, as the latter directly benefit from these cuts while the former do not. However, interestingly enough our simulations in Figure B.1 show that hand-to-mouth agents expand their consumption significantly more in the near and medium term than optimizing households when this policy is implemented in a long-lasting liquidity trap (blue solid line). In this situation, hand-to-mouth households labor income increases a lot due to the expansionary impact of this policy. Optimizing households find it worthwhile to invest in the capital stock, which eventually enables them to increase their consumption relative to hand-to-mouth consumers (see the effects in periods 60-100). In a normal situation, the red dotted line shows that the consumption of poor agents is very similar to that of rich households in the short and medium term, but in the longer term we again find that the lower capital income tax benefits savers, who can afford higher levels of consumption than hand-to-mouth households.

B.2.2. Temporary Sales Tax Cut

In Figure B.2, we redo the experiment in Figure 5 where instead of a gradual sales tax hike we implement a temporary sales tax cut. In this case, we consider the same-sized changes in the sales tax, but assume an AR(1) process with persistence 0.8 (as opposed to the AR(2) process used for the results discussed in the main text). Relative to the baseline findings in Figure 5, the output response is more positive under a non-aggressive tax rule whereas a balanced-budget rule is associated with a lower output response for temporary sales tax cut. So a temporary sales tax cut is more effective in boosting output than a gradual sales tax hike if the labor tax is not adjusted aggressively to balance the budget. The opposite finding holds for an balanced-budget rule.

Figure B.1: Sales Tax Hike with Balanced-Budget Capital Tax Rule in TANK Model.

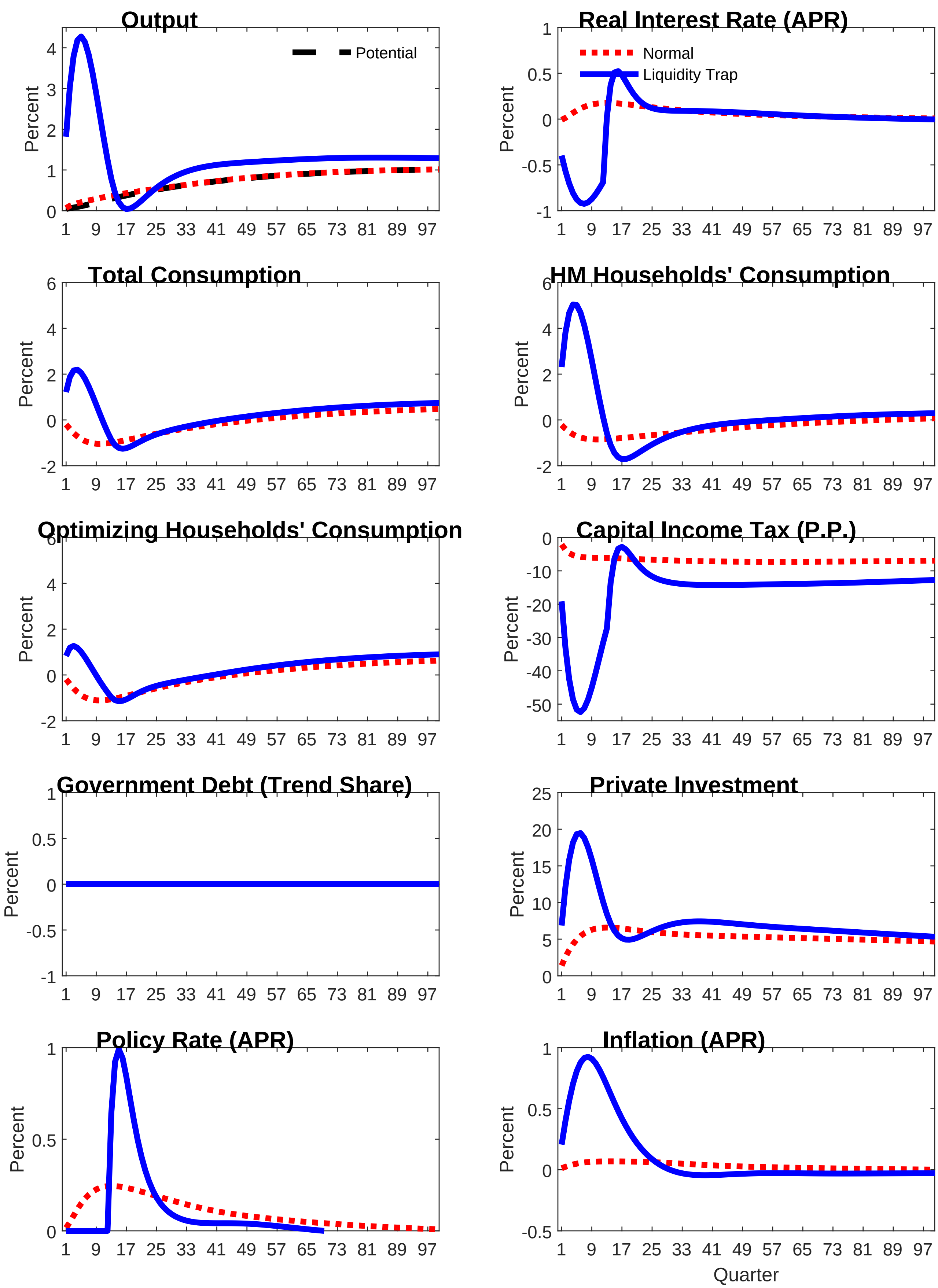
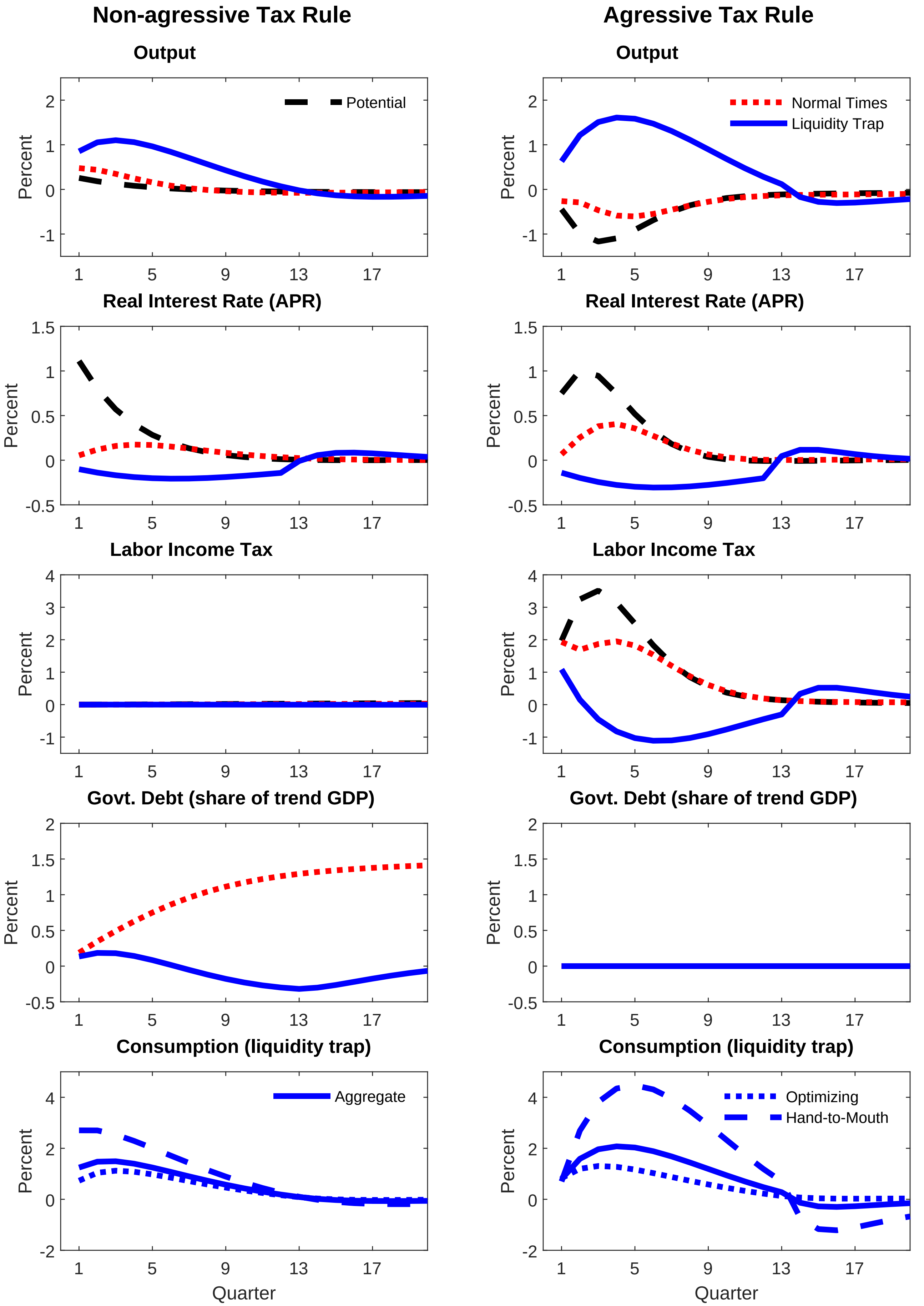


Figure B.2: Impulses to a Transient Sales Tax Cut in the TANK model.



Appendix C. Robustness in a Model with Durable Goods

In this appendix, we show that our key findings hold when allowing for durable goods in the model. While we have examined the robustness of the results with durables goods in both the stylized sticky price model in Section 2 and the fully-fledged TANK model in Section 4, here we report results only for the fully-fledged TANK model. Results for the stylized model with durable goods are available upon request. Below we first briefly outline how we have introduced durable goods into the model and our calibration choice of the parameters pertaining to the durable goods features of the model. Next, we show the effects of the two policy tools (higher sales tax/public investment spending). In the durable goods model, we assume that the sales tax pertains to both durable and non-durable goods. For the case with higher public investment spending, we assume that higher government spending pertains exclusively to durables, as durables are exclusively used to build the capital stock.

C.1. Modeling of Durable Goods

In this subsection, we describe how the model has been augmented with durables consumption. We start with households, and then move on to the government. Next, we discuss production of services and durable goods, and finally aggregate resource constraints.

C.1.1. Households

Optimizing Households The utility functional for an optimizing representative member of household h is similar to the utility functional (B.9) in the TANK model, but it now distinguishes the utility of non-durables consumption $C_t^O(h)$ from the stock of durables D_t^O:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left\{ \frac{1-\gamma}{1-\sigma} \left(C_{t+j}^O(h) - \varkappa_C C_{t+j-1}^O - C^O \nu_{Ct} \right)^{1-\sigma} + \frac{\gamma}{1-\sigma} \left(D_{t+j}^O(h) - \varkappa_D D_{t+j-1}^O - D^O \nu_{Dt} \right)^{1-\sigma} - \frac{\chi_0}{1+\chi} N_{t+j}(h)^{1+\chi} \right\}, \tag{C.1}$$

where the parameter γ quantifies the relative weight of the utility provided by durables, the parameter $\varkappa_D$ quantifies habits with respect to this specific good, whereas ν_{Dt} is an exogenous stochastic preference shifter of durables.

Aggregated labor $N_t(h)$ is a CES bundle of labor in the services sector $N_{C,t}(h)$ and labor in the durable/investment goods sector $N_{X,t}(h)$:

$$N_t(h) = \left[N_{C,t}(h)^{1+\chi\mu} + N_{X,t}(h)^{1+\chi\mu} \right]^{\frac{1}{1+\chi\mu}}$$

This specification nests two polar cases depending on the value of the parameter μ between 0 and 1[C.1]. If $\mu = 0$, labor is fully mobile between sectors: $N_t(h) = N_{C,t}(h) + N_{X,t}(h)$. If $\mu = 1$, labor is fully immobile, because the utility becomes separable with respect to each type of labor: $N_t(h)^{1+\chi} = N_{C,t}(h)^{1+\chi} + N_{X,t}(h)^{1+\chi}$. In this case, labor supply choices are isolated from each other: there is no substitution of labor across sectors or, in other words, an increase of labor in one sector will have no direct negative effect on the labor supply in the other sector. Because of the imperfect mobility of labor, for each sector $j \in \{C, X\}$, optimizing households set a specific nominal wage $W_{j,t}(h)$ and each wage-setting is based on Calvo-style staggered contracts as in the TANK model.

The flow budget constraint in eq. (B.10) for optimizing household h is changed to:

$$\begin{gathered} P_{Ct}(1+\tau_{Ct})\, C_t^O(h) + P_{Xt}(1+\tau_{Ct})\, X_t^O(h) + P_{Xt} I_t(h) + P_{Xt}\left(\psi_{C,It}(h) + \psi_{X,It}(h) + \psi_{O,Xt}(h)\right) \\ + P_{Bt} B_{Gt+1} - B_{Gt} + \int_s \xi_{t,t+1} B_{Dt+1}(h) - B_{Dt}(h) \\ = (1-\tau_{Nt})\left(W_{C,t}(h) N_{C,t}(h) + W_{X,t}(h) N_{X,t}(h)\right) + (1-\tau_{Kt})\left(R_{C,Kt} K_{C,t}(h) + R_{X,Kt} K_{X,t}(h)\right) \\ + P_{Xt-1}\tau_{Kt}\delta\left(K_{C,t}(h) + K_{D,t}(h)\right) + \Gamma_t(h) - T_t(h), \end{gathered} \tag{C.2}$$

where τ_{Ct} denotes the sales tax on private consumption of services and purchases of durables $X_t^O(h)$ and $I_t(h)$ is investment used for the production of each type of good, i.e. $I_t(h) = I_{C,t}(h) + I_{D,t}(h)$. Note that we now distinguish the price of durables P_{Xt} from the price of non-durables P_{Ct}.

The stock of durables $D_t^O(h)$ evolves according to

$$D_t^O(h) = (1-\delta_D)\, D_{t-1}^O(h) + X_t^O(h),$$

i.e. there is no time-to-build. We allow for direct effects on durables in order for the model to nest the benchmark model without durables when $\delta_D = 1$. Investment in physical capital is based only on durable goods and it augments per capita capital stock $K_{C,t+1}(h)$ and $K_{D,t+1}(h)$ according to linear transition laws in the form of equation (B.11). We denote their adjustment costs $\psi_{j,It}(h)$ for $j \in \{C, X\}$, with the same functional form as in the TANK model.

Following Erceg and Levin (2006), we also assume that it is costly to change the level of durables and we do it in a similar way as that chosen for investment goods:

$$\psi_{O,Xt}(h) = \frac{1}{2}\psi_X \frac{\left(X_t^O(h) - X_{t-1}^O(h)\right)^2}{X_{t-1}^O(h)}. \tag{C.3}$$

[C.1] We borrow this specification from Boehm (2019).

Keynesian (Hand-to-Mouth) Households We now consider the determination of the consumption of services and durables and labor supply of hand-to-mouth (HM) households. HM households simply equate their nominal consumption spending, $P_{Ct}\left(1+\tau_{Ct}\right) C_t^{HM}(h)+P_{Xt}\left(1+\tau_{Ct}\right) X_t^{HM}(h)$, based on two types of goods instead of the one-good setup, to their income in equation (B.16):

$$P_{Ct}\left(1+\tau_{Ct}\right) C_t^{HM}(h)+P_{Xt}\left(1+\tau_{Ct}\right) X_t^{HM}(h)=\left(1-\tau_{Nt}\right)\left(W_{C,t}(h) N_{C,t}(h)+W_{X,t}(h) N_{X,t}(h)\right)+TR_t(h)-T_t(h) \tag{C.4}$$

HM households are assumed to work for the average wage of forward-looking households. Since HM households face the same labor demand schedule as forward-looking households, each HM household works the same number of hours as the average for forward-looking households, as in Erceg, Guerrieri, and Gust (2006) and Galí, López-Salido and Vallés (2007).

Now, a complication of eq. (C.4) is that it does not pin down the division of consumption into $C_t^{HM}(h)$ and $X_t^{HM}(h)$. To do that in a simple and reasonable way, we assume HM households maintain the same ratio between services and durables as optimizing households do in the steady state, i.e.

$$C_t^{HM}(h) / \left(P_{X,t} X_t^{HM}(h)\right)=C^O / \left(P_X X^O\right). \tag{C.5}$$

Together, eqs. (B.16) and (C.5) determine $C_t^{HM}(h)$ and $X_t^{HM}(h)$.

C.1.2. Government

With durables in the model, the government budget constraint becomes

$$\begin{aligned} P_{Bt} B_{Gt+1}-B_{Gt}= & P_{Ct} G_{Ct}+P_{Xt} G_{It}-T_t-\tau_{Ct} P_{Ct}\left[(1-\varsigma) C_t^O+\varsigma C_t^{HM}\right]-\tau_{Ct} P_{Xt}\left[(1-\varsigma) X_t^O+\varsigma X_t^{HM}\right] \\ & -\tau_{Nt}\left(W_{C,t} N_{C,t}+W_{X,t} N_{X,t}\right)-\tau_{Kt}(R_{KCt}-\delta P_{Xt-1}) K_{C,t}^P-\tau_{Kt}(R_{KXt}-\delta P_{Xt-1}) K_{X,t}^P . \end{aligned} \tag{C.6}$$

Compared with equation (B.12) in the non-durables model, equation (C.6) distinguishes receipts of the sales tax depending on the type of spending, and those of the labor income and capital income tax depending on the sectors. Note also that the nondurable price is used for government consumption and the durable price is used for government investment, because we assume here that government consumption and investment are respectively based on nondurable and durable goods.

C.1.3. Firms and price-setting

Final Goods Production We assume that both types of goods $Y_{j,t}$ for $j \in \{C, X\}$ are produced using a continuum of differentiated intermediate goods $Y_{j,t}(f)$. The technology for transforming these intermediate goods into the final output good is constant returns to scale, and is of the Kimball form:

$$\int_0^1 G_Y\left(\frac{Y_{jt}(f)}{Y_{j,t}}\right) df = 1 \tag{C.7}$$

where

$$G_Y\left(\frac{Y_{j,t}(f)}{Y_{j,t}}\right) = \frac{1+\theta_p}{1-\theta_p\epsilon_p}\left[\left(\frac{1+\theta_p-\theta_p\epsilon_p}{1+\theta_p}\right)\frac{Y_{j,t}(f)}{Y_{j,t}} + \frac{\theta_p\epsilon_p}{1+\theta_p}\right]^{\frac{1-\theta_p\epsilon_p}{1+\theta_p-\theta_p\epsilon_p}} + \left[1 - \frac{1+\theta_p}{1-\theta_p\epsilon_p}\right]$$

and $\theta_p > 0$ and $\epsilon_p > 0$. For the sake of parsimony, we assume here that these markup and curvature parameters are common across durable and nondurable sectors.

Intermediate Goods Production For each sector $j \in \{C, X\}$, the intermediate goods producer utilizes capital services $K^{tot}_{j,t}(f)$, again based on private and public capital, and a labor index $L_{j,t}(f)$ to produce its respective output good. As in equation (B.4), the production function of each sector is Cobb-Douglas:

$$\begin{aligned} Y_{j,t}(f) &= Z_{j,t}K^{tot}_{j,t}(f)^{\alpha}L_{j,t}(f)^{1-\alpha}, & \text{(C.8)} \\ K^{tot}_{j,t}(f) &= \left(K^{P}_{j,t}(f)\right)^{\vartheta}\left(K^{G}_{t}\right)^{1-\vartheta}. & \text{(C.9)} \end{aligned}$$

For each sector $j \in \{C, X\}$, the prices of the intermediate goods are determined by Calvo-Yun style staggered nominal contracts, with dynamic indexation as in the TANK model. Again, for the sake of parsimony, we assume that the indexation parameter ι_p is common across both sectors. Conversely, because of empirical evidence of heterogeneity on this side, we allow for the possibility of asymmetries across sectors with respect to the Calvo probability, which we denote $\xi_{j,p}$ for each sector $j \in \{C, X\}$.

C.1.4. Aggregate resource constraints

As government consumption is based on non-durables, total output in the non-durables sector is subject to the following resource constraint:

$$Y_{Ct} = C_t + G_{Ct} \tag{C.10}$$

Finally, as government and private investment are based on durables, total output in the durables sector is subject to the following resource constraint:

$$Y_{Xt} = X_t + I_t + G_{It} + \psi_{C,It} + \psi_{X,It} + \psi_{O,Xt} \tag{C.11}$$

where $\psi_{C,It}$, $\psi_{X,It}$ and $\psi_{O,Xt}$ are the adjustment costs aggregated across all households.

C.1.5. Calibration

Most parameters are set to the same values as in the TANK model without durables. However, the durables model includes a few additional parameters, and we briefly motivate their calibration here. First, we set the weight of durable goods in the utility function (γ) to 0.2 in order to get a steady state share of durable goods in total consumption of 18%, which is close to the average share for the United States.[C.2] Second, we set the depreciation rate of the stock of durable goods (δ_D) at 0.035, i.e. an annualized value of 14% which is also consistent with historical data for the United States.[C.3] Third, we set the adjustment cost parameter of durables (ψ_X) to 0.15, which allows us to get the same relative effect on durables and non-durables after a monetary policy shock as in Erceg and Levin (2006).[C.4] Fourth, while we first present results when the speed of price and wage adjustment in the durables and non-durables sectors are the same, we then allow for an asymmetric calibration with faster price adjustment in the durables sector as suggested by the empirical literature on micro data. Specifically, we set the Calvo parameter of durables at $\xi_{X,p} = 0.83$ (compared to $\xi_{C,p}$= **0.89** for non-durables).[C.5]

Shares of government consumption in non-durable output and of government investment in durable output are set at values (28.5 and 10.2 percent, respectively), such that their shares in total output equal the same values as in the non-durables TANK model (20 and 3 percent, respectively). Given that we set all public finance variables at the same values as in the TANK model, the government's intertemporal budget constraint implies that the labor income tax rate τ_N equals 0.357 in steady state, i.e. the same value as in the non-durables TANK model.

[C.2] More specifically, as in Erceg and Levin (2006), we rely here on a broad definition of durable goods, which also includes residential investment. In the United States, the average share of such goods equals 17.7% between 1980-2018, which we round to 18%.

[C.3] In the United States, over the 1980-2018 sample, the average depreciation rate of consumer durable goods and residential investment are equal to 19.7% and 2.2% respectively. As the share of consumer durable goods equals 66%, the weighted depreciation rate of these two types of goods is equal to 13.8%, which we round to 14%.

[C.4] Following Erceg and Levin (2006), we set the adjustment cost parameter to obtain a peak response of durable output after a monetary policy shock five times larger than the output of non-durables.

[C.5] Based on BLS micro data on the US CPI, Bils and Klenow (2004) document that prices for goods are changed more often than for services: the implied mean duration between price changes for durables are 2/3 of the mean duration for services. In accordance with this evidence, we calibrate the Calvo probability for durables (0.83) such that the corresponding implied mean duration (around 6 quarters) is 2/3 of that for non-durables which is around 9 quarters, given our calibration of the Calvo probability for non-durables to **0.89**.

C.2. Higher Sales Taxes

In Figure C.1, we show the effects of a same-sized sales tax hike as in Figure 5 in the model with durable goods. Importantly, we assume that the higher sales tax is imposed on both non-durable and durable goods. The left-hand column in the figure shows the results when we assume the same degree of price adjustment in both sectors, whereas the right-hand column shows the results for the calibration with faster price adjustment in the durables sector (supported by the micro evidence). Panel A reports results for the non-aggressive labor tax rule, and Panel B the corresponding findings for the balanced-budget tax rule.

By comparing the results in Figure C.1 with those in Figure 5, we see that the introduction of durable goods greatly increases the stimulative effects of the sales tax hike, especially with a slower degree of price adjustment under a balanced-budget rule. Even in the case with a non-aggressive tax rule and faster price adjustment, we observe an increase in economic activity and crowding in of consumption during the first year. However, the economic benefits are significantly higher if the sales tax hike is combined with a cut in labor income taxes, echoing the findings in the TANK model without durables.

C.3. Higher Public Investment

In Figure C.2, we show the effects of the same-sized increase in public investment in the model with durables, to be compared with the impulses in the workhorse model without durables (Figure 7). Importantly, higher public investment spending is here comprised exclusively of durable goods. The figure is structured the same way as the previous figure.

By comparing the results in Figure C.2 with those in Figure 7, we see that the introduction of durable goods significantly elevates the output multipliers of a same-sized increase in public investment under the calibration with the same speed of price adjustment. So not only does the introduction of durables induce a larger impact of a sales tax hike, it also induces much greater effects of higher government investment. And as regards a non-aggressive tax rule, higher public investment is still more expansionary than a hike in the sales tax. Even if we allow for faster price adjustment for durable goods, we find that the short-run output multiplier remains above two with a non-aggressive rule and above one with a balanced-budget rule. Thus, we believe the analysis in the model with durables corroborates our key findings in the benchmark model without durables: higher public investment is a robust conventional policy to expand the economy in a liquidity trap, and it could be complemented with unconventional policy in the form of a gradual increase in the sales tax (and lower labor income taxes).

Figure C.1: Sales Tax Hike in the Model with Durables.

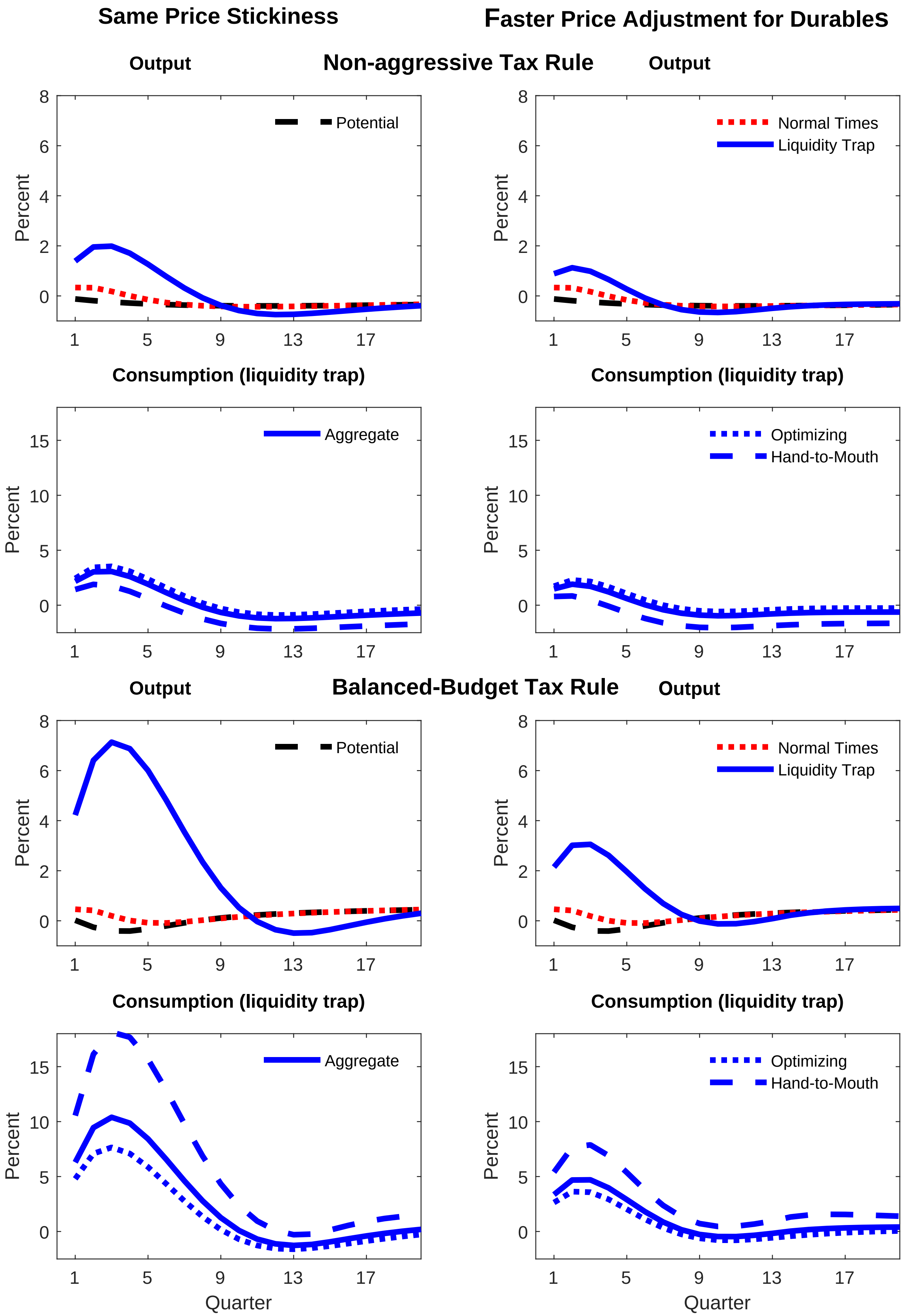


Figure C.2: Higher Public Investment in the Model with Durables.