# Optimal Conventional Stabilization Policy in a Liquidity Trap When Wages and Prices are Sticky*

Adiya Belgibayeva
EBRD

Michal Horvath†
University of Oxford

January 2014

**Abstract**

We study an economy in which it is optimal not to use expected inflation as a stabilization tool in or out of the liquidity trap. In such a world, the well-known conventional stabilization mix should be applied more forcefully: the forward commitment regarding interest rates should apply for even longer, and government spending should 'lean against the wind' more vigorously. This policy strategy generates a real economy boom in the future and helps stabilizing demand in the short run. Tax policy plays a key role in ensuring price stability. This is generally consistent with a short-run income tax hike counteracting deflationary pressures. The initial government spending expansion is thus close to a balanced-budget one.

**JEL Classification**: E31, E32, E52, E61, E62.
**Keywords**: Zero Lower Bound, Sticky Wages, Inflation Stabilization, Income Tax, Government Spending.

*Acknowledgements: We are grateful for the comments received at various stages from Guido Ascari, Martin Ellison, Campbell Leith, Charles Nolan, Antonio Mele, Ioana Moldovan, Tim Willems, Simon Wren-Lewis and Francesco Zanetti. We would also like to thank Taisuke Nakata for his help with the solution methodology.

†Corresponding author. Department of Economics and Nuffield College, University of Oxford, Manor Road Building, Manor Road, Oxford OX1 3UQ, United Kingdom, E-mail: michal.horvath@economics.ox.ac.uk

# 1. Introduction

We study the optimal coordination of fiscal and monetary policies in an economy subject to price and wage rigidities caught in a liquidity trap. The presence of imperfect nominal wage adjustment prevents anticipated inflation from being used as a stabilization tool. On the other hand, we show that it justifies a commitment by authorities to keep the interest rate at zero for longer as well as a stronger countercyclical response in government spending.

In a benchmark contribution to the literature, Correia et al. (2013) have shown that a sufficiently rich set of tax instruments can completely circumvent the liquidity trap problem, and may even enable policy makers to implement the first best outcome. In principle, the optimal policy involves a sustained consumption tax increase to generate costless (in the context of the model) consumer price inflation that lowers the real interest rate sufficiently to fully stabilize demand. At the same time, other taxes ensure that costly producer price and wage inflation do not arise, and that the fiscal solvency requirement is satisfied. This paper, as much of the literature, studies a world in which solutions that are costless in welfare terms are ruled out. In addition to setting the tax on wage income, the authorities can only use forward commitment concerning interest rates and changes in valued government spending to stabilize the economy in a liquidity trap. We refer to such a policy strategy as the conventional stabilization mix. Such a set of policy tools also better reflects the policy decisions implemented by central banks and governments around the developed world in the wake of the most recent severe recession.[1]

Krugman (1998) famously argued that monetary policy is not ineffective in a

[1] See, for example, European Commission (2009) or Council of Economic Advisers (2010). Only the United Kingdom have on a one-off basis implemented a policy concerning the general VAT rate that is vaguely in line with Correia et al. (2013).

liquidity trap as long as it is able to affect inflation expectations. Higher inflation expectations lower the current real interest rate and act to stimulate demand even if the short-term nominal interest rate is stuck at zero. It has been shown in the context of standard New Keynesian models that the monetary policy consistent with such evolution of prices involves a commitment to keep the nominal interest rate at zero for some time after the zero bound ceases to bind.[2] There are, however, important cases when expected inflation is too costly to be used as a stabilization channel. This is the case when there are nominal wage rigidities in addition to price rigidities present in the economy.[3] This paper shows that monetary policy still has a role to play even in such an environment. The optimal monetary policy involves a commitment to keep the interest rates at zero for even longer. This contributes to a boom in the real economy in the future which reduces desired savings and stimulates demand in the short run. This is consistent with a thought experiment in Werning (2012) who examined the case of a simple economy in a liquidity trap with artificially fixed prices. We show that such a simple exercise is a close approximation of optimal dynamics in a sticky-price sticky-wage New Keynesian economy.[4]

We also show that in these circumstances, the other element of the conventional stabilization mix must be applied more forcefully too: the desired short-term

[2]See, for example, Eggertsson and Woodford (2003), Jung et al. (2005) and Adam and Billi (2006).

[3]Imperfect nominal wage adjustment is a standard building block in medium-scale New Keynesian models. The fact that optimal inflation variability drops in such a world relative to a world with flexible wages is well documented. See, for instance, Chugh (2006). In the sense of Cochrane (2013), the presence of sticky wages also acts as an equilibrium selection device, significantly narrowing down the set of equilibria one might wish to implement.

[4]In addition to such theoretical appeal, the study of environments in which inflation as a demand stabilization channel is shut down is interesting from a practical perspective too. Inflation expectations on both sides of the Atlantic have been remarkably stable throughout the crisis as documented by data from the Survey of Professional Forecasters as well as the ECB's preferred measures of inflation expectations (see Figure A.1).

government spending expansion is significantly larger and the government must commit itself to greater cuts in the future. A policy strategy in which government spending is first raised and then cut whilst the nominal interest rate is at the zero bound has been proposed by Gertler (2003) due to its impact on the natural rate of interest. Nakata (2011) and Werning (2012) have shown this to be a feature of optimal policy in a liquidity trap.

To complete the policy mix, labour income tax policy plays a crucial role in ensuring price stability, as in Correia et al. (2013). However, unlike in Correia et al. (2013), given that the policy mix is different, this role is generally consistent with a short-term tax increase. The idea that an income tax hike is desirable at the zero bound due to its effect on (expected) inflation and the real interest rate has been discussed in Benigno (2009), Eggertsson (2011) and Nakata (2011). However, their demand-driven rationale for tax hikes is not what drives tax policy in our model. Instead, the motivation for the tax increase here is to stabilize prices, countering the deflationary pressures arising from depressed demand and the wealth effect of the enacted government spending increase. Overall, the budgetary impact of stabilization measures is close to zero in the short term.

In our quantitative analysis, we find that the model-consistent welfare costs of applying the best conventional policy mix relative to implementing the optimal unconventional tax policy strategy of Correia et al. (2013) are small even though the associated short-term real contraction is large. We also look at the welfare costs of erring on the size of the government spending expansion. We study the extreme case in which government spending is held constant throughout the recession, whilst the interest and tax rates are set optimally. The optimal nominal interest rate path and the inflation trajectory remain virtually unaffected. The short-run losses in real income are somewhat higher but the overall welfare costs of inaction on government spending are not large.

The model in the paper is a New Keynesian setup with sticky prices, sticky wages and endogenous income tax policy. This economy is subject to a large fundamental shock as a result of which optimally set nominal interest rates hit the zero lower bound.[5] Eggertsson and Woodford (2006) and Nakata (2011) have also studied a simultaneous determination of optimal monetary and fiscal policy in a deep recession but wages remained flexible in their frameworks. Christiano et al. (2009) and Christiano (2010), whilst including wage stickiness, only examined the functioning of ad hoc (tax) policies and concentrated on the implied real economy effects finding that the fiscal multipliers can be large. Cochrane (2013) argues this is a consequence of equilibrium selection rather than an inherent feature of policy in a liquidity trap. We also calculate implied fiscal multipliers using our exercise when government spending is held constant, and find that the government spending multiplier under optimal policy is not unusually large.

The rest of the paper is organized as follows. Section 2 introduces the model that forms the basis for our analysis of the design of optimal monetary and fiscal policies in a liquidity trap. This model is parameterized and solved using the nonlinear method explained in great detail in Nakata (2011). The results of the numerical exercise are presented and related to the existing literature in Section 4. Section 5 concludes.

## 2. The model

This section describes a model of an economy with sticky nominal wages and prices akin to Benigno and Woodford (2005) which builds on Erceg et al. (2000).

[5] The policy prescriptions obtained in our framework are standard given that the source of the downturn in our model is also standard—a shock to the rate of time preference of agents. Schmitt-Grohé and Uribe (2013) and Mertens and Ravn (2013) have questioned the usefulness of such conventional policy advice if the cause of the severe downturn in the economy is that expectations are not well-anchored. We believe this discussion is beyond the scope of the intended contribution of this paper.

The framework allows us to consider the special case of an economy with an efficient steady state but we will also relax the assumption that there are subsidies available to eliminate steady-state distortions caused by imperfect competition. The government authorities in our economy set the interest rate, government spending and the distortive labor income tax rate to stabilize the economy. Shocks to the discount factor are the only source of disturbance in the model, and we examine the economy's adjustment along a deterministic path following a single large innovation to the discount factor. If this innovation was small, it could be fully offset by a cut in the nominal interest rate, and other policy instruments would not play a role in stabilizing the economy.

Whilst the model is closer to the widely used medium-scale setups than the more common simple stylized frameworks in terms of its complexity, it should still be thought of only as a relatively tractable environment for the study of policy interactions. The quantitative results from this model are especially subject to this caveat. The main lessons concerning policy coordination should, however, apply more generally, as the circumstances we examine are implicit in all larger-scale models.

### 2.1. The discount factor shock

An exogenous shock to the discount factor of agents, representing a change in their preferences in terms of consumption and savings, is used to capture the idea of a severe demand-led contraction in the economy. When an economy is hit by the discount factor shock, consumers suddenly decide to postpone consumption. Under a very severe shock a cut in nominal interest rate down to zero will not stabilize the economy at its original level, and output and prices have to fall.

As in Nakata (2011), we assume that the discount factor at time $t+s$ is defined as $\beta\delta_s$, i.e. $\delta_s$ shows the relative difference between discount factors at time $t+s$

and $t+s+1$. An increase in $\delta_s$ implies that households want to reduce consumption and save more. The following assumptions about the discount factor shock hold in the model

$$\begin{aligned}\delta_0 &= 1,\\ \delta_1 &= 1+\varepsilon_{\delta,1},\\ \delta_s &= 1+\rho_\delta\left(\delta_{s-1}-1\right) \text{ for } s \geqslant 2.\end{aligned}$$

The discount factor shock is realized before optimization decisions are made. It holds that $\varepsilon_{\delta,1} > 0$ and the shock persists, but decays with the time at the rate $0 < \rho_\delta < 1$.

### 2.2. Households and the labour market

There is a continuum of monopolistically competitive households $j \in [0,1]$ in the economy. They choose private consumption of a final good $C_t(j)$ and holdings of one-period risk-free nominal government bond $B_t(j)$ to maximize welfare given by

$$E_t \sum_{s=0}^{\infty} \beta^s \prod_{k=0}^{s} \delta_k \left[\frac{C_{t+s}(j)^{1-\chi_C}}{1-\chi_C} - \chi_{N,0}\frac{N_{t+s}(j)^{1+\chi_{N,1}}}{1+\chi_{N,1}} + \chi_{G,0}\frac{G_{t+s}(j)^{1-\chi_{G,1}}}{1-\chi_{G,1}}\right]$$

subject to the constraint

$$P_{t+s}C_{t+s}(j) + \frac{B_{t+s}(j)}{R_{t+s}} \leqslant (1-\tau_{n,t+s})W_t^* N_{t+s}(j) + B_{t+s-1}(j) - T_t^{LS}. \tag{2.1}$$

It is thus assumed that the households derive benefits from government spending, and that the utility is separable in terms of consumption, labor supply and government spending. The variable $P_t$ is a price of a final good, $R_t$ stands for the gross nominal return on the bond, while $\tau_{n,t}$ is the labor income tax rate. $T_t^{LS}$ refers to the lump sum taxes (transfers) that may be paid by (to) the households. This maximization exercise yields the Euler equation

$$C_t^{-\chi_C} = E_t \beta \delta_t R_t C_{t+1}^{-\chi_C} \Pi_{t+1}^{-1}, \tag{2.2}$$

where $\Pi_t = P_t/P_{t-1}$ is price inflation. The Euler equation is not indexed by the households, as we assume completeness of insurance market against idiosyncratic shocks and that the initial holdings of assets are the same across households. Therefore, $C_t(j) = C_t$ for all $j$ and $t$.[6]

Each of the households supplies a differentiated labor service $N_t(j)$ at a wage rate $W_t(j)$. There is a perfectly-competitive employment agency that aggregates the supplied differentiated labor in an index according to the standard Dixit-Stiglitz formula

$$N_t = \left[ \int_0^1 N_t(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

in which $\varepsilon$ is the elasticity of substitutions between differentiated labour. The perfectly-competitive employment agency sells aggregated labour to producers of final goods at an aggregate wage index $W_t$. The agency chooses $N_t(j)$ to maximize nominal profits $W_t N_t - \int_0^1 W_t(j) N_t(j)$, taking each household's wage rate $W_t(j)$ and the aggregate price index $W_t$ as given. In optimum, the employment agency's demand for the household $j$'s labour is given by

$$N_t(j) = N_t \left[ \frac{W_t(j)}{W_t} \right]^{-\varepsilon}. \tag{2.3}$$

The aggregate wage index is then given by

$$W_t = \left[ \int_0^1 W_t(j)^{1-\varepsilon} dj \right]^{\frac{1}{1-\varepsilon}}.$$

To introduce wage stickiness, the model assumes a system of staggered wage contract for the households: each household is able to change their wages with probability $1-\xi_w$ at any given period of time. Whenever the household is allowed to re-optimize its wage, it chooses optimal $W_t^*$ to maximize expected discounted sum of utilities, taking into account that it may not be allowed change its wage,

[6] Notice here that if $\delta$ is small enough, it can be fully offset by a change in $R$, leaving the rest of the economy unaffected.

subject to the demand for labor and the budget constraint. If the household has not been allowed to re-optimize its wage since period $t$, it sets $W_{t+s} = W_t$. For simplicity, we do not consider wage indexation.[7] The household thus chooses $W_t^*$ to maximize

$$E_t \sum_{s=0}^{\infty} (\xi_w \beta)^s \prod_{k=0}^{s} \delta_k \left[ \frac{C_{t+s}(j)^{1-\chi_C}}{1-\chi_C} - \chi_{N,0} \frac{N_{t+s}(j)^{1+\chi_{N,1}}}{1+\chi_{N,1}} + \chi_{G,0} \frac{G_{t+s}(j)^{1-\chi_{G,1}}}{1-\chi_{G,1}} \right]$$

subject to (2.1) and (2.3). This problem gives us the wage setting equation

$$(w_t^*)^{1+\varepsilon\chi_{N,1}} = \frac{\varepsilon}{\varepsilon-1} \frac{N_{n,t}}{N_{d,t}}, \tag{2.4}$$

where $w_t^* = W_t^*/W_t$ with

$$N_{n,t} = \chi_{N,0} N_t^{1+\chi_{N,1}} + E_t \beta \delta_t \xi_w \left(\Pi_{t+1}^w\right)^{\varepsilon\left(1+\chi_{N,1}\right)} N_{n,t+1}, \tag{2.5}$$

$$N_{d,t} = w_t N_t C_t^{-\chi_C} (1-\tau_{n,t}) + E_t \beta \delta_t \xi_w \left(\Pi_{t+1}^w\right)^{\varepsilon-1} N_{d,t+1}. \tag{2.6}$$

We have defined $\Pi_t^w = W_t/W_{t-1}$ and $w_t = W_t/P_t$. Given our wage setting mechanism, the evolution of the aggregate wage index follows

$$1 = (1-\xi_w)(w_t^*)^{1-\varepsilon} + \xi_w (\Pi_t^w)^{\varepsilon-1}. \tag{2.7}$$

### 2.3. Firms

There is a continuum of intermediate differentiated goods $Y_t(i)$, $i \in [0,1]$, each of which is produced by a monopolistically competitive firm using a linear production function

$$Y_t(i) = N_t(i). \tag{2.8}$$

The price of an intermediate good $i$ is $P_t(i)$. Assume there is a final good producer that operates in a perfectly competitive environment selling $Y_t$ which

[7] This feature could reinforce the persistence in real wages.

is an aggregate of $Y_t(i)$ according to

$$Y_t = \left[ \int_0^1 Y_t\left(i\right)^{\frac{\theta-1}{\theta}} di \right]^{\frac{\theta}{\theta-1}}, \tag{2.9}$$

in which $\theta$ is the elasticity of substitutions between the differentiated intermediate products. The final goods producing firm sells its product to the consumers at a price $P_t$. It chooses the quantity of each differentiated good to maximize its profit $P_t Y_t - \int_0^1 P_t(i) Y_t(i) di$. As a result, demand for intermediate good $i$ is given by

$$Y_t\left(i\right) = Y_t \left[ \frac{P_t(i)}{P_t} \right]^{-\theta}. \tag{2.10}$$

The price aggregate price index is given by

$$P_t = \left[ \int_0^1 P_t\left(i\right)^{1-\theta} di \right]^{\frac{1}{1-\theta}}.$$

Price adjustment is assumed to be staggered too. It is assumed that in any given period the intermediate goods producing firm is able to re-optimize its price with a probability $1 - \xi_p$. Whenever a firm is able to re-optimize its price it chooses the optimal $P_t^*$ to maximize expected discounted sum of profits subject to the demand for its product defined in equation (2.9). Similarly to the households, we assume that there is no price indexation, and hence if the intermediate goods producing firm has not been allowed to re-optimize its price since period $t$, it sets $P_{t+s} = P_t$ in period $t + s$. The problem of the firm is thus

$$\begin{aligned} &\max_{P_t^*} E_t \sum_{s=0}^{\infty} \left(\xi_p \beta\right)^s \prod_{k=0}^{s} \delta_k \left[P_{t+s}^* - W_{t+s}\right] Y_{t+s}\left(i\right) \\ &s.t.\ (2.9). \end{aligned}$$

The solution for the optimal price is given by

$$p_t^* = \frac{\theta}{\theta - 1} \frac{C_{n,t}}{C_{d,t}}, \tag{2.11}$$

where $p_t^* = P_t^*/P_t$ with

$$C_{n,t} = w_t Y_t C_t^{-\chi_C} + E_t \beta \delta_t \xi_p \Pi_{t+1}^{\theta} C_{n,t+1}, \tag{2.12}$$

$$C_{d,t} = Y_t C_t^{-\chi_C} + E_t \beta \delta_t \xi_p \Pi_{t+1}^{\theta-1} C_{d,t+1}. \tag{2.13}$$

The dynamic of the aggregate price index follows

$$1 = \left(1 - \xi_p\right) \left(p_t^*\right)^{1-\theta} + \xi_p \Pi_t^{\theta-1}. \tag{2.14}$$

### 2.4. Government

Monetary and fiscal authorities coordinate their action to maximize social welfare. The monetary branch of the central government sets the nominal interest rate $R_t$, and is constrained by the zero lower bound

$$R_t \geqslant 1 \text{ for all } t. \tag{2.15}$$

The fiscal authority sets the tax rate $\tau_{n,t}$ and decides about government spending $G_t$. The government flow budget constraint tracking the evoution of debt is then given by

$$\frac{b_t}{R_t} = \frac{b_{t-1}}{\Pi_t} - \tau_{n,t} w_t N_t + G_t - T_t^{LS}. \tag{2.16}$$

### 2.5. Market clearing

Given the intermediate goods producing firms' production function (2.8), the demand for intermediate goods (2.10), and the labor market clearing condition $N_t = \int_0^1 N_t\left(i\right) di$, it can be shown that

$$Y_t = N_t s_t \tag{2.17}$$

where

$$s_t = \int_0^1 \left[\frac{P_t(i)}{P_t}\right]^{-\theta} di = \left(1 - \xi_p\right) \left(p_t^*\right)^{-\theta} + \xi_p \Pi_t^{\theta} s_{t-1} \tag{2.18}$$

stands for price dispersion. The resource constraint is given by

$$C_t + G_t = Y_t. \tag{2.19}$$

An important equilibrium condition is the identity describing the evolution of real wages in the economy

$$\frac{w_t}{w_{t-1}} = \frac{\Pi_t^w}{\Pi_t}. \tag{2.20}$$

Chugh (2006) highlights the importance of this identity in generating endogenous persistence in a sticky-price, sticky-wage economy. Given that the wage inflation is influenced by the wage setting behavior of households, the price inflation, instead, by the price setting behavior of firms, and the real wage is determined by the real factors, this identity represents a constraint on the optimal policy problem, as the wage and the price inflation are not trivially consistent with it.

### 2.6. The policy problems

We shall consider several environments with an increasing degree of complexity. In all cases, the objective will be to find sequences of endogenous variables that maximize an unweighted average of welfare across households

$$W_t = E_t \sum_{s=0}^{\infty} (\beta)^s \prod_{k=0}^{s} \delta_k \left[ \frac{{C_{t+s}}^{1-\chi_C}}{1-\chi_C} - \chi_{N,0} \frac{{N_{t+s}}^{1+\chi_{N,1}}}{1+\chi_{N,1}} m_{t+s} + \chi_{G,0} \frac{G_{t+s}^{1-\chi_{G,1}}}{1-\chi_{G,1}} \right],$$

where

$$\begin{aligned} m_t &= \int_0^1 \left[ \frac{W_t(j)}{W_t} \right]^{-\varepsilon\left(1+\chi_{N,1}\right)} dj \\ &= (1-\xi_w) \left(w_t^*\right)^{-\varepsilon\left(1+\chi_{N,1}\right)} + \xi_w \left(\Pi_t^w\right)^{\varepsilon\left(1+\chi_{N,1}\right)} m_{t-1} \end{aligned} \tag{2.21}$$

is a measure of wage dispersion.

We shall be looking for policies that are optimal from a timeless perspective (Woodford, 2003). In other words, we will be solving for time-invariant policy rules assuming that preferences in the initial period are augmented so that the policy maker does not take advantage of the fact that there had been no expectations formed about the initial outcomes.

**Case FBFW: Efficient steady state and flexible wages.** In this economy, the steady-state value of the tax rate $\tau_n$ is set to eliminate distortions that arise from monopolistic competition. An appropriate lump-sum tax $T_t^{LS}$ ensures that the government budget constraint holds in every period. Moreover, $m_t = 1$ for all $t$. The constraints of the policy problem are the equilibrium conditions (2.2), (2.14), (2.15), (2.17), (2.18) and the (2.19).

**Case FBSW: Efficient steady state and sticky wages.** This economy is the same as the one we have just described but $m_t \neq 1$ for all $t$. The constraints of the problem are the equilibrium conditions (2.2), (2.7), (2.11), (2.12), (2.13), (2.14), (2.15), (2.17), (2.18), (2.19) and (2.21). The equations (2.4), (2.5), (2.6) then imply the optimal tax policy. Equation (2.20) defines the evolution of real wages.

**Case FBP: Strict price-level targeting in Case FBFW.** This economy is the same as in Case FBFW but we add the restriction that the price level remains constant in the economy. The economy, including the zero-bound constraint, thus becomes real. The constraints of the policy problem are the equilibrium conditions (2.2), (2.15), (2.17) and (2.19), with $P_t = s_t = 1$ for all $t$.

*Tax policy and price stability.* Notice here from (2.11), (2.12), (2.13) and (2.14) that in order for prices to remain stable, real wages have to stay flat. In order for that to happen, (2.4), (2.5), (2.6) and (2.7) tell us that the tax rate has to track the evolution of the marginal rate of substitution between consumption and leisure. This allows us to draw the conclusion about the key role of taxation in ensuring price stability. This is the same reasoning as in Correia et al. (2013).

**Case SBFW: Distorted steady state and flexible wages.** In this economy, lump sum taxes are no longer available to ensure the government budget constraint is satisfied ($T_t^{LS} = 0$ for all $t$). Therefore the relevant constraints are (2.2), (2.11), (2.12), (2.13), (2.14), (2.15), (2.16), (2.17), (2.18), (2.19) and the transversality condition. We also consider a variant of this economy in which $G_t = \overline{G}$ for all $t$ where $\overline{G}$ is the steady-state values of government spending.

**Case SBSW: Distorted steady state and sticky wages.** Lump sum taxes are again unavailable ($T_t^{LS} = 0$ for all $t$), and the relevant constraints are the equilibrium conditions (2.2), (2.4), (2.5), (2.6), (2.7), (2.11), (2.12), (2.13), (2.14), (2.15), (2.16), (2.17), (2.18), (2.19), (2.20), (2.21) and the transversality condition. As above, we also consider the variant with $G_t = \overline{G}$ for all $t$.

### 2.7. Welfare evaluations

We will conduct welfare comparisons and in order to do so, we introduce a welfare metric. Our starting point is a hypothetical one-off transfer in real consumption units in the initial period that would make the agent in a given economy as well off as in a benchmark economy. This one-off transfer can then be re-stated as a perpetuity value of a sequence of identical per-period transfers discounted by the steady-state interest rate. Our welfare gains and losses will then be measured as the share of such hypothetical per-period transfers on steady-state consumption.

Formally, let us define $W^*$ as the level of welfare in the benchmark economy and $W$ as the level of welfare in the economy under consideration. The one-off transfer of real consumption $\Delta_t$ will be implicitly defined as follows

$$\Delta_t = \left[ (1-\chi_C) \left( W_t^* - W_t + \frac{{C_t}^{1-\chi_C}}{1-\chi_C} \right) \right]^{\frac{1}{1-\chi_C}} - C_t.$$

From this, the per-period value of the consumption transfer is given by $\Delta_t (1-\beta)/\beta$. Finally, we obtain the welfare measure reported below $d_t = (1-\beta)\Delta_t/\beta\overline{C}$, where $\overline{C}$ refers to the steady-state level of consumption.

Let us further define $W^{FB}$ as the level of welfare that would be observed should the economy with an efficient steady state and lump-sum taxes always remain in its steady state. This hypothetical case is the first-best solution of Correia et al. (2013). Similarly, we can define $W^{SB}$ as the level of welfare that would be observed in the economy with a distorted steady state, should it always stay in its steady state. Again, following Correia et al. (2013), a sufficiently rich set of tax instruments could accomplish this in our framework. When comparing economies against $W^{FB}$ or $W^{SB}$, the steady-state values of consumption corresponding to the respective bechmark economy will be used in the welfare metric $d_t$.

## 3. Parameterization and solution

We parameterize the model with values commonly used in the literature.[8] The discount factor $\beta$ is assumed to be 0.99. The discount factor shock $\varepsilon_{\delta,1}$ is set to 0.02 to make sure the economy hits the zero bound. The persistence of the innovation $\rho_\delta$ is 0.9. Thus, to determine when the natural rate of interest exceeds zero, one needs to check at what quarter the product of $\beta\delta_t$ falls below 1. For the parameters of the shock process, the discount factor and the persistence, the natural rate of interest is above zero from t>7.[9] We assume preferences are

[8] The parameter values are summarized in Table A.1 in the appendix.

[9] Werning (2012) shows this need not be equivalent to the point in time when the zero bound stops binding, as the optimal interest rate reaction function may involve other terms that are

logarithmic in government spending but set $\chi_C$ to 1/6 and the inverse Frisch elasticity of labour supply to 1.[10] The preference parameters $\chi_{N,0}$ and $\chi_{G,0}$ are set to 1 and 0.2 respectively. This parameterization implies that steady-state government spending is at 21 percent of steady-state output and the steady-state public debt close to 50 percent of annualized GDP. The elasticity of susbstitution for goods $\theta$ is set to 11. We follow Chugh (2006) in setting the elasticity of substitution in the labour market $\varepsilon$ to 21. The measure of price stickiness $\xi_p$ is 0.75 implying an average four-quarter duration or price contracts. The same value is used to parameterize the duration of wage contracts when wages are sticky.[11]

Given that we consider an event in which the economy departs far from its steady state, and an inequality constraint becomes binding, we solve the model in its non-linear form. We use the procedure described in detail in Nakata (2011), which embeds the modified Newton method of Juillard et al. (1998) into a shooting algorithm. As shown in Nakata (2011) there are significant accuracy gains from using a nonlinear solution relative to piecewise linear methods.

## 4. Results

We find that the optimal policy mix in our model is very much in line with the convetional policy prescription of Krugman (1998) and Gertler (2003) but only when wages are flexible. When prices only are sticky and the cost of inflation variability is thus moderate, it is optimal in the liquidity trap to allow inflation to rise temporarily, and let public sector spending lean against the wind. This is shown in Figure A.2. Interest rates are kept at zero even after the natural rate

non-zero at the zero bound in addition to the natural rate. We only have a numerical solution for the interest rate, and so cannot be more precise here.

[10] This is a value used in Jung et al. (2005), Nakata (2011), and is close to the estimate of Rotemberg and Woodford (1997).

[11] In the flexible-wage case, we set this parameter to zero but retain imperfect competition in the labour market so that the flexible-wage and sticky-wage economies are easier to compare.

crosses the zero bound. This policy mix generates a boom in the real economy in the future, and helps containing the slump in the short run.

It is a well-known fact that optimal inflation volatility drops with the introduction of rigidities in nominal wage adjustment. Hence, the inflation expectations channel cannot be used to boost demand to the same extent as in the flexible wage economy. We show that under conventional stabilization, the dynamic of the optimal sticky-wage economy is for all practical purposes the same as the dynamic of an economy without price or nominal wage inflation.[12] This, however, does not imply that monetary policy is ineffective in stabilizing the economy. The optimal monetary policy is similar to the one in an environment with flexible wages: it involves a forward commitment to keep the interest rates at zero for a prolonged period of time. The difference is that such a commitment should now apply even longer (11 quarters versus 9, in our case). Moreover, in the context of a world with essentially no inflation, the magnitude of the optimal initial government spending increase almost doubles, whilst the government must promise to cut spending deeper in the future. This policy strategy again generates a boom in the economy in the future which reduces desired savings in the short run. Werning (2012) has argued that policies in the liquidity trap are geared towards generating an expected real economy boom rather than inflation per se, and this is confirmed here by our analysis.

We have argued above that taxation plays a crucial role in ensuring price stability in the model. The tax in our economy is the tax on labour income levied on the individual. This tax directly affects marginal cost, and is therefore an effective instrument deployed to deliver the desired evolution of prices.[13] Since

[12] See Figure A.2 for the efficient steady state case and Figure A.3 for the case when the steady state of the economy is distorted. The differences are negligible.

[13] Obviously, tax policy has a role to play in ensuring fiscal sustainability too. But the comparison of the optimal economies with and without lump-sum taxes suggests that this role is quantitatively less important.

the sticky-wage economy is a close approximation of the economy with fixed prices and wages, it holds that the tax rate closely tracks the evolution of the marginal rate of substitution between consumption and leisure. This view of the role of tax policy is the same as in Correia et al. (2013). Taxes generally rise in the short-term in our model but the rationale for this is different from the demand-side considerations found in the literature. In particular, Benigno (2009), Eggertsson (2011) and Nakata (2011) sought to justify tax increases through their impact on (expected) inflation and the real interest rate. This is in turn different from Bils and Klenow (2008) who concentrated on the income effect of a tax cut, which is the reasoning probably closest to the philosophy behind similar real-world stimulus measures. In our model, taxes rise to counteract the deflationary pressures arising from depressed demand and the negative wealth effect of the increase in government spending. The overall budgetary impact of stabilization measures is close to zero initially, as seen from Figure A.4, which plots the optimal dynamics of fiscal variables in cases SBFW and SBSW.

Correia et al. (2013) have shown that given a sufficiently rich set of taxes, one can always circumvent the zero-bound problem and ensure the economy never leaves its first-best steady state. Our conventional policy mix cannot achieve this. However, when the conventional policy is executed in the best possible way, it delivers welfare consistent with a welfare loss relative to the first-best steady state of less than 0.4 percent of steady-state consumption when wages are flexible and around 0.6 percent with sticky wages. As also shown in Table A.2, the same conclusion holds in the context of an economy with a distorted steady state. Short-term losses in real private consumption and income are, however, large in particular in the sticky-wage economy.

We also look at the welfare cost of not being bold enough on the government spending side and it appears limited too (see Table A.2). At the same time, there are significant short-term real economy implications: output contracts by two percentage points more. In Figure A.3, we compare dynamics under optimal policy in the SBSW case with what would happen should government spending be held constant. We see that optimal interest rate and inflation dynamics are little affected but output is affected significantly.

Finally, we calculated the implied government spending multiplier by looking at cases SBFW and SBSW under alternative paths for government spending, whilst maintaining that the remaining policy tools are deployed optimally.[14] Figure A.5 plots the cumulative real increase in output divided by the cumulative real increase relative to steady state in the level of government spending at various time horizons discounted by the steady state interest rate. We see that the magnitude of the multipliers is not unusually large.

## 5. Conclusions

We have shown that given the low optimal inflation volatility when price and wage adjustment is imperfect, expected inflation cannot be used to cut real interest rates further and stabilize demand in a liquidity trap. This, however, does not mean monetary policy is ineffective even under these circumstances. We have shown that by committing itself to keep the interest rate at zero for even longer than otherwise, the monetary authority can stabilize demand at present by generating a boom in the future. The optimal conventional policy mix involving a significant short-term increase in government spending in addition to the action on the interest rate was shown not to generate large welfare losses relative to the world when the policy maker has enough tax instruments to fully stabilize the economy. This holds in spite of the fact that we observe a significant drop in real output in the short term.

[14] We focus on the government spending multiplier, since we argue that the tax policy serves a different purpose in our setup, and the multiplier calculations would thus be counterintuitive.

It is an interesting exercise to check the robustness of this quantitative conclusion in medium-scale models involving a lot more nominal and real inertia.

We have also shown that a (close-to-)balanced-budget expansion of government spending is the optimal conventional stabilization policy, and it should be deployed more forcefully when the desired inflation volatility is low. An increase in government spending followed by a cut boosts demand when expected inflation cannot, whilst the increase in the income tax rate offsets deflationary pressures. The government spending multiplier associated with such a policy is not unusually large.

Throughout the paper, we have referred to model-consistent preferences which are indeed central to our welfare analysis. Some may have legitimate doubts if the welfare analysis based on preferences built into standard New Keynesian frameworks provides a good reflection of the costs of business cycles, and if the implied policy prescriptions should indeed be taken seriously. Obviously, there is a lot more work to be done in the broadest sense to build better models to study economic cycles and their welfare consequences. The smallest departure from the present setup would be to have a model with a better account of the welfare costs of unemployment or financial market failures. Nevertheles, our paper allows the reader to have a better understanding of the policy trade-offs in environments with different relative costs of nominal versus real volatility.

## References

[1] Adam, K. and R. M. Billi, 2006, Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates, Journal of Money, Credit and Banking, 38(7), 1877-1905.

[2] Benigno, P., 2009, New-Keynesian Economics: An AS-AD View, NBER Working Paper No. 14824.

[3] Benigno, P. and M. Woodford, 2005, Inflation Stabilization and Welfare: The Case of a Distorted Steady State, Journal of the European Economic Association, 3, 6, 1185-1236.

[4] Bils, M. and P. Klenow, 2008, Further Discussion of Temporary Payroll Tax Cut During Recession(s), mimeo.

[5] Christiano, L., M. Eichenbaum, and S. Rebelo, 2009, When is the government spending multiplier large?, NBER Working Paper No. 15394.

[6] Christiano, L. J., 2010, Comment on Eggertsson, "What fiscal policy is effective at zero interest rates?", CQER Working Paper 2010-06, Federal Reserve Bank of Atlanta.

[7] Chugh, S. K., 2006, Optimal Fiscal and Monetary Policy with Sticky Wages and Sticky Prices, Review of Economic Dynamics 9(4), 683-714.

[8] Cochrane, J.H., 2013, The New-Keynesian Liquidity Trap, NBER Working Paper No. 19476.

[9] Correia I., Farhi, E., Nicolini, J.P. and P. Teles, 2013, Unconventional Fiscal Policy at the Zero Bound, American Economic Review, 103(4), 1172-1211.

[10] Council of Economic Advisers, 2010, The Economic Impact of the American Recovery and Reinvestment Act of 2009, Fourth quarterly report.

[11] Eggertsson, G. B.: 2011, What Fiscal Policy is Effective at Zero Interest Rates?, in: NBER Macroeconomics Annual 2010, Volume 25, pages 59-112

[12] Eggertsson, G. B. and M. Woodford, 2003, The Zero Bound on Interest Rates and Optimal Monetary Policy, Brookings Papers on Economic Activity 34(1), 139-235.

[13] Eggertsson, G. B. and M. Woodford: 2006, 'Optimal Monetary and Fiscal Policy in a Liquidity Trap'. in: NBER International Seminar on Macroeconomics 2004, pages 75-144

[14] Erceg, C. J., D. W. Henderson, and A. T. Levin: 2000, Optimal monetary policy with staggered wage and price contracts, Journal of Monetary Economics, 46(2), 281-313.

[15] European Commission, 2009, The EU's Response to Support the Real Economy During the Economic Crisis: an Overview of Member States' Recovery Measures, European Economy, Occasional Papers No. 51.

[16] Gertler, M., 2003, Comments on: "The Zero Bound on Interest Rates and Optimal Monetary Policy by Eggertston and Woodford", mimeo.

[17] Juillard, M., D. Laxton, P. McAdam, and H. Pioro, 1998, An algorithm competition: First-order iterations versus Newton-based techniques, Journal of Economic Dynamics and Control, 22(8-9), 1291-1318.

[18] Jung, T., Y. Teranishi, and T. Watanabe, 2005, Optimal Monetary Policy at the Zero-Interest-Rate Bound, Journal of Money, Credit and Banking, 37(5), 813-35.

[19] Krugman, P. R., 1998, It's Baaack: Japan's Slump and the Return of the Liquidity Trap, Brookings Papers on Economic Activity 29(2), 137-206.

[20] Mertens, K. and M.O. Ravn, 2013, Fiscal Policy in an Expectations Driven Liquidity Trap, mimeo.

[21] Nakata, T., 2011, Optimal Government Spending at the Zero Bound: Nonlinear and Non-Ricardian Analysis, mimeo.

[22] Rotemberg, J.J. and M. Woodford, 1997, An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy, in: Bernanke, B.S. and J.J. Rotemberg, NBER Macroeconomics Annual, 12, 297-346.

[23] Schmitt-Grohé, S. and M. Uribe, 2013, The Making of a Great Contraction with a Liquidity Trap and a Jobless Recovery, mimeo.

[24] Werning, I., 2012, Managing a Liquidity Trap: Monetary and Fiscal Policy, mimeo.

[25] Woodford, M., 2003, Interest and Prices: Foundations of a Theory of Monetary Policy, Princeton University Press.

# A. Appendix: Figures and Tables

Figure A.1: Inflation expectations in the US and euro area (annual pct. rate, source: Survey of Professional Forecasters, ECB)

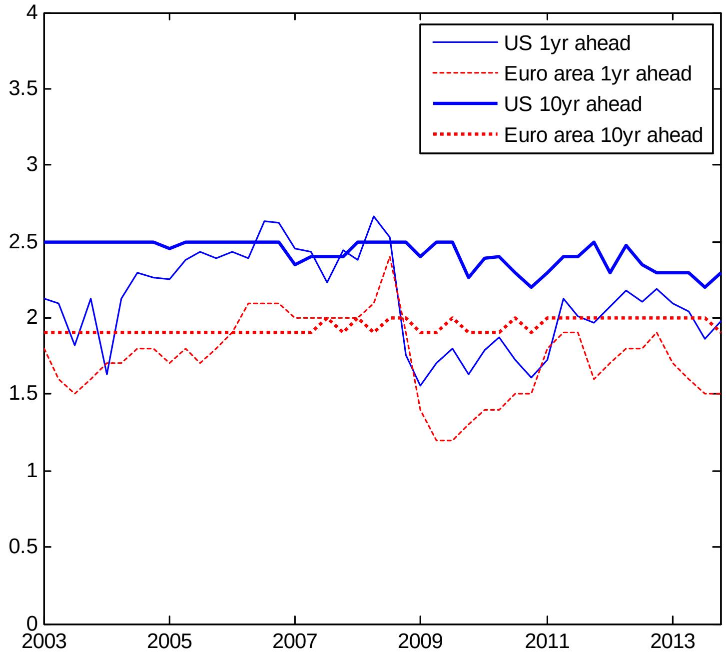

Figure A.2: Impulse response functions of endogenous variables in economies with an efficient steady state and different price and wage adjustment mechanisms (deviations from steady state)

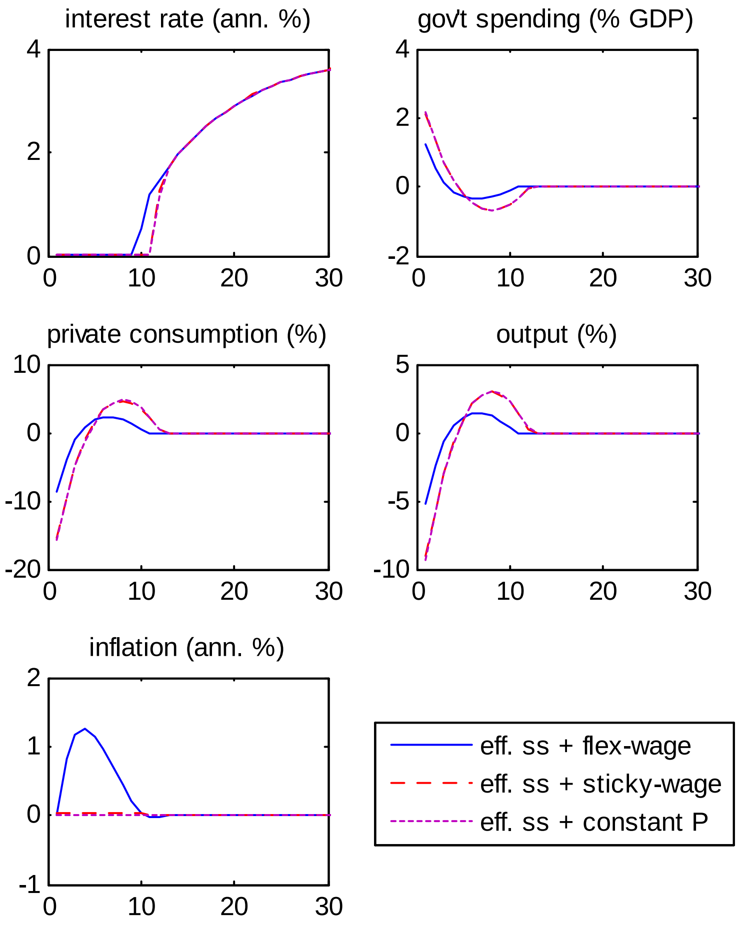

Figure A.3: Impulse response functions of key endogenous variables under optimal policy and in an economy with fixed government spending (Case SBSW, deviations from steady state)

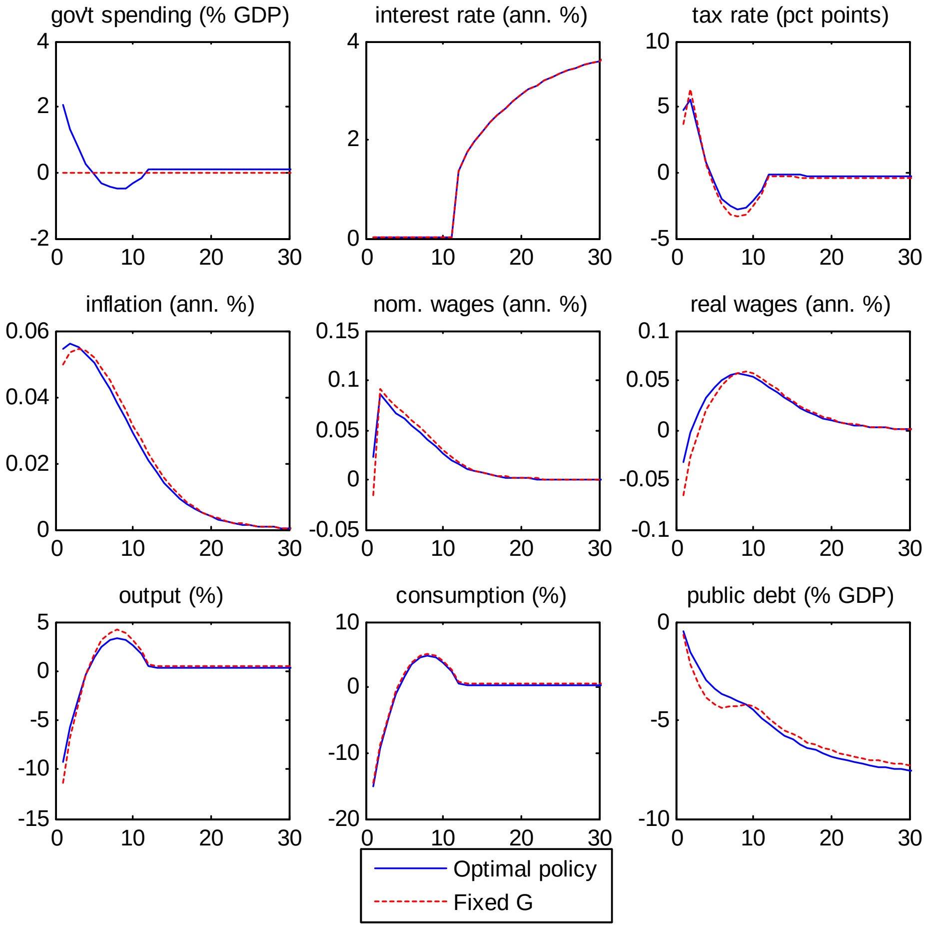

Figure A.4: Impulse response functions of key fiscal variables under optimal policy

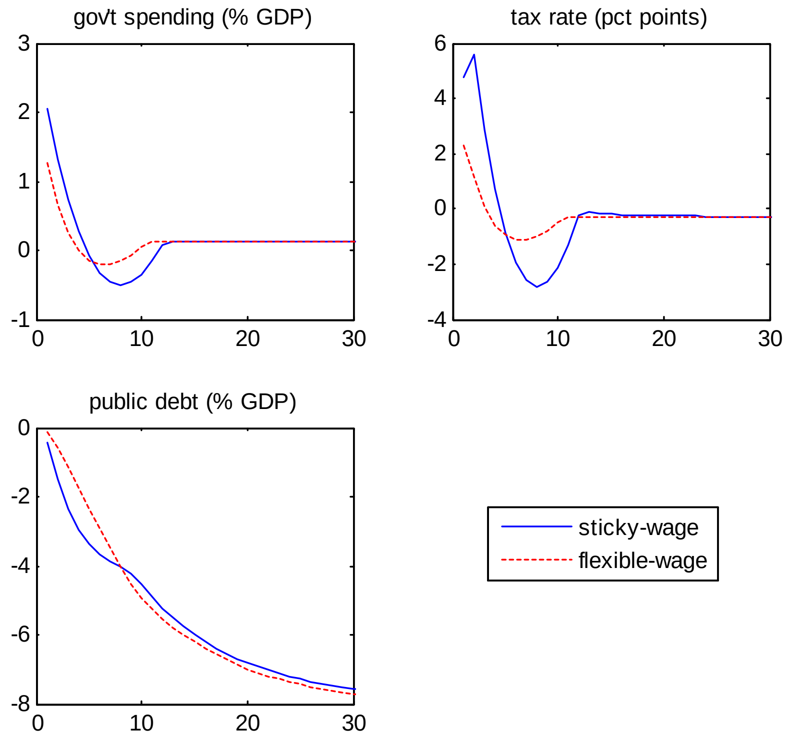

Figure A.5: Implied government spending multipliers over different horizons

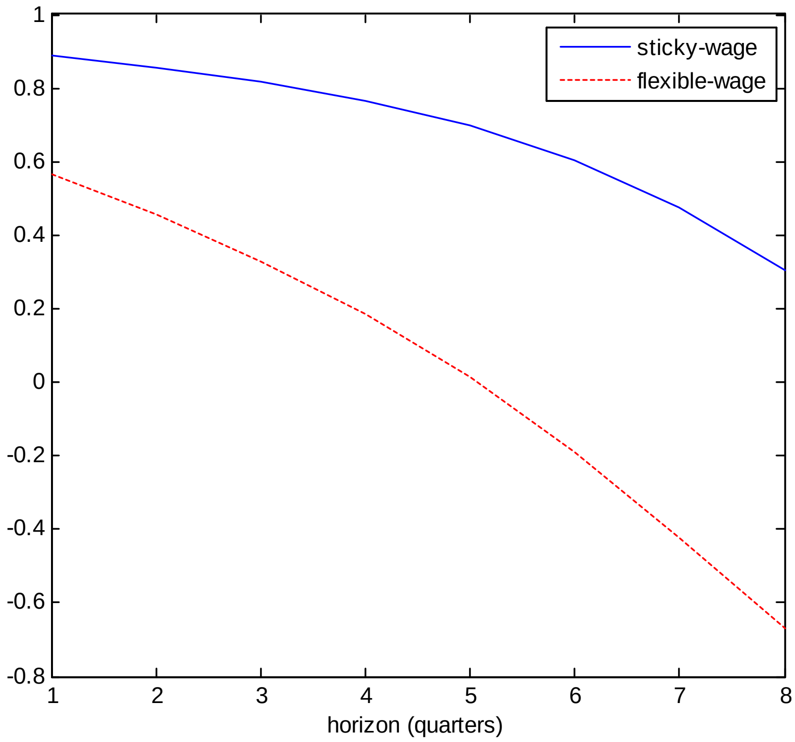

Table A.1: Parameter values

| Notation | Description | Value |
|---|---|---|
| $\beta$ | discount factor | 0.99 |
| $\chi_C$ | coefficient of relative risk aversion | 1/6 |
| $\chi_{N,0}$ | leisure preference parameter | 1 |
| $\chi_{N,1}$ | inverse Frisch elasticity of labour supply | 1 |
| $\chi_{G,0}$ | government spending preference parameter | 0.2 |
| $\chi_{G,1}$ | government spending preference parameter | 1 |
| $\theta$ | elasticity of substitution in the goods market | 10 |
| $\varepsilon$ | elasticity of substitution in the labour market | 21 |
| $\xi_p$ | probability of no price adjustment | 0.75 |
| $\xi_w$ | probability of no wage adjustment | 0.75 |
| $\varepsilon_{\delta,1}$ | shock to the discount factor | 0.02 |
| $\rho_\delta$ | persistence of the shock | 0.90 |

Table A.2: Welfare losses

| Economy | Utility value | $d_t$ (%) |
|---|---|---|
| First-best (steady state) | 20.382 | – |
| Case FBFW | 20.074 | 0.38 |
| Case FBSW | 19.881 | 0.63 |
| Case FBP | 19.874 | 0.64 |
| Second-best (steady state) | 14.018 | 9.99 |
| Second-best (steady state) | 14.018 | – |
| Case SBFW | 13.819 | 0.33 |
| Case SBFW + constant G | 13.806 | 0.35 |
| Case SBSW | 13.607 | 0.69 |
| Case SBSW + constant G | 13.541 | 0.81 |