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ON THE OPTIMAL MIX OF FISCAL AND MONETARY POLICY ACTIONS

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ABSTRACT

We study optimized monetary and fiscal feedback policy rules. The setup is a conventional New Keynesian DSGE model calibrated to match data from the euro area. Our aim is to welfare rank alternative tax-spending policy instruments used for shock stabilization and/or debt consolidation when, at the same time, the monetary authorities follow a Taylor rule for the interest rate.

Keywords: Feedback policy rules, New Keynesian.
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1 Introduction

Policymakers use their instruments to react to economic conditions. For instance, it is usually assumed that central banks respond to inflation, the fiscal authorities to the state of public finances, and both of them to real economic activity. It is also believed that the use of fiscal policy is more complex than the use of monetary policy. As e.g. Leeper (2010) points out, one reason is that, while central banks have a single instrument at their disposal at least in normal times, namely, the nominal interest rate, governments can make use of many types of spending and tax policy instruments. But different fiscal policy instruments have different implications (see e.g. Coenen et al., 2012).

In this paper, we search for the best mix of monetary and fiscal policy actions when the policy role is twofold: to stabilize the economy against shocks and to improve resource allocation by gradually reducing the public debt burden over time. In order to do so, we welfare rank various fiscal policy instruments used jointly with interest rate policy.

In particular, we specify feedback rules for public spending as share of output, the tax rate on labor income, the tax rate on capital income and the tax rate on consumption that allow for a response to a number of macroeconomic variables used as indicators, when, at the same time, monetary policy can be used in a standard Taylor-type fashion. We optimally choose the indicators that the fiscal and monetary authorities should react to, as well as the magnitude of feedback policy reaction to those indicators. The welfare criterion is household's expected lifetime utility. This type of policy is known as "optimized policy rules" (see e.g. Schmitt-Grohé and Uribe, 2005, 2007). We work within two environments. In the first, the economy is hit by supply and demand shocks, which means that we solve a pure stabilization policy problem. In the second, the fiscal authorities also aim at gradually reducing the output share of public debt over time, which means that now we combine shock stabilization with resource allocation policy.

The setup is a standard New Keynesian model of a closed economy featuring imperfect competition and Calvo-type nominal rigidities, which is extended to include a rather rich menu of state-contingent policy rules. The model is calibrated to match data from the euro area over 1995-2010. To solve the model and, in particular, to solve for welfare-maximizing policy, we adopt the methodology of Schmitt-Grohé and Uribe (2004), in the sense that we take a second-order approximation to both the equilbrium conditions and the welfare criterion. In turn, we compute the welfare-maximizing values of various feedback policy rules and the associated social welfare. This enables us to welfare rank alternative policies in a stochactic setup.

Our main results are as follows. First, concerning fiscal instruments, it is better to use public spending, rather than taxes, for shock stabilization and/or debt consolidation. In all cases studied, public spending scores the best in terms of expected lifetime utility, being followed by consumption taxes, then capital taxes and lastly labor taxes. Labor taxes are clearly the worst policy instrument to make use of.

Second, in all cases studied, the monetary authorities should react to price inflation and the fiscal authorities should react to public debt. In terms of magnitudes, the interest rate reaction to price inflation should be aggressive, namely, more than one-for-one as also implied by the Taylor principle, while the fiscal reaction to public debt should be mild in general (even in the case of debt consolidation), except from the case in which we use the capital tax rate. The latter happens because, in the very short run, the capital tax can work like a capital levy on existing wealth which is not so distorting relative to other taxes (see Chamley, 1986, and Judd, 1985, as well as the simulations of Altig et al., 2001, who have studied tax reforms in the US).

Third, monetary and fiscal policy reaction to the output gap is in general welfare-improving, other things equal. In other words, counter-cyclical fiscal policy is productive (this modifies the "consensus assignment" of e.g. Gordon and Leeper, 2005, and Kirsanova et al., 2009, and supports the arguments of Wren-Lewis, 2010, for the use of active fiscal policy in an economic downturn). This holds especially when extrinsic volatility is relatively high. It also holds even in the case of debt consolidation. The latter (namely, that policy reaction to the output gap is desirable even when the fiscal authorities want to bring the public debt ratio down) is explained by the fact that, since debt consolidation strategies may hurt the real economy, monetary and fiscal policy also need to be alert in real economic activity at the same time.

Fourth, except from the case in which we use a particularly distorting policy instrument like the labor tax rate, debt consolidation is welfare superior to non debt consolidation, other things equal. This is despite the fact that debt consolidation comes at the cost of lower public spending, or higher taxes, during the early phase of the transition period. Also, the duration of the debt consolidation period, and so how quickly the debt should be brought down, depends on which fiscal instrument we use. The more distorting is the instrument used, the longer the period should be. For instance, if we use the public spending ratio to reduce the debt ratio from 85% to 60%, this should be within 40 quarters. At the other end, if we use the labor tax rate, it should take more than 100 quarters.

Fifth, since, in most cases, it is optimal for policy instruments to respond to several indicators at the same time, the central issue is which response should be the dominant one. It is the latter that will shape the net change in a particular policy instrument. Say, for instance, that the economy is hit by an adverse TFP shock causing at impact an economic downturn and a rise in the inherited public debt to output ratio. Then, in normal times during which macro volatility is relatively low and shock stabilization is the only policy goal, our impulse response functions show that, at impact, public spending should fall, and capital taxes should rise, to address the rise in the debt ratio. By contrast, consumption and labor taxes should be reduced at impact to address the fall in output. In other words, when, for some political economy reason, we have to use a relatively distorting policy instrument, like consumption and especially labor taxes, net policy changes should be dominated by the concern for output cycles and only over the medium term, when the adverse shock fades away, these policy instruments should be used to address debt cycles. These results become stronger when macro volatility is relatively high. Actually, now, all fiscal policy instruments, including public spending and capital taxes, should give priority to the output cycle over the short term. Nevertheless, these results are reversed when public debt consolidation is added to the policy goals. Now, irrespectively of the degree of macro volatility, all fiscal policy instruments should be earmarked for bringing the public debt ratio down, even during the early phase of economic downturn, and, as said above, this is welfare superior other things equal, except if we have to use a particularly distorting policy instrument like labor taxes.

How does our work differ? Although there has been a rich literature on the interaction between fiscal and monetary policy,[1] there has not been a welfare comparison of all main tax-spending policy instruments in a unified framework, and how this comparison depends on the degree of extrinsic volatility and/or the policy goals.[2]

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 presents the data, calibration and the long-run solution. Section 4 explains how we work. Section 5 studies the case with shock stabilization only. Section 6 studies the case with shock stabilization and debt consolidation. Section 7 closes the paper.

[1] See e.g. Leeper (1991), Schmitt-Grohé and Uribe (2005 and 2007), Leith and Wren-Lewis (2008) and Leeper et al. (2009). For reviews, see e.g. Kirsanova et al. (2009), Wren-Lewis (2010) and Leeper (2010).

[2] Papers related to ours include Schmitt-Grohé and Uribe (2007), Batini et al. (2008), Bi (2010), Bi and Kumhof (2011), Herz and Hohberger (2012) and Cantore et al. (2012). Some details are as follows. Schmitt-Grohé and Uribe (2007) allow total tax revenues to respond to public debt. But they do not welfare rank different fiscal policy instruments. The same applies to Batini et al. (2008) who allow tax revenues as share of output to react to public debt and output. Bi (2010) does welfare rank different tax policy instruments. But she works in a real small open economy without monetary policy. Also, she allows the tax rates to respond to public debt only. Bi and Kumhof (2011) focus on the importance of liquidity-constrained households. Also, they do not rank different tax-spending feedback policy rules. Herz and Hohberger (2012) include monetary policy but, concerning fiscal policy, they only use public spending for stabilization. They also work in a linear-quadratic setup with an ad hoc policy objective function. Cantore et al. (2012) have a rich analysis studying optimal policy in abnormal times, but they assume that all tax policy instruments change by the same proportion. They also work with a linear-quadratic approximation.

2 Model

The model is a conventional New Keynesian model featuring imperfect competition and Calvo-type nominal rigidities, which is extended to include a rather rich menu of state-contingent policy rules.[3]

2.1 Households

There are $i = 1, 2, ..., .N$ households. Each household i acts competitively to maximize expected lifetime utility.

2.1.1 Household's problem

Household i's expected lifetime utility is:

$$E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_{i,t}, n_{i,t}, m_{i,t}, g_t\right) \tag{1}$$

where $c_{i,t}$ is i's consumption bundle (defined below), $n_{i,t}$ is i's hours of work, $m_{i,t} \equiv \frac{M_{i,t}}{P_t}$ is i's real money balances, g_t is per capita public spending, $0 < \beta < 1$ is the time discount rate, and E_0 is the rational expectations operator conditional on the current period information set.

In our numerical solutions, we use the period utility function (see also e.g. Gali, 2008):

$$u_{i,t}\left(c_{i,t}, n_{i,t}, m_{i,t}, g_t\right) = \frac{c_{i,t}^{1-\sigma}}{1-\sigma} - \chi_n \frac{n_{i,t}^{1+\eta}}{1+\eta} + \chi_m \frac{m_{i,t}^{1-\mu}}{1-\mu} + \chi_g \frac{g_t^{1-\zeta}}{1-\zeta} \tag{2}$$

where χ_n, χ_m, χ_g, σ, η, μ, ζ are preference parameters.

The period budget constraint of each household i is in nominal terms**:**

$$\begin{aligned} &\left(1+\tau_t^c\right) P_t c_{i,t} + P_t x_{i,t} + B_{i,t} + M_{i,t} = \\ &\left(1-\tau_t^k\right)\left(r_t^k P_t k_{i,t-1} + D_{i,t}\right) + \left(1-\tau_t^n\right) W_t n_{i,t} + R_{t-1} B_{i,t-1} + M_{i,t-1} - T_{i,t}^l \end{aligned} \tag{3}$$

where P_t is the general price index, $x_{i,t}$ is i's real investment, $B_{i,t}$ is i's end-of-period nominal government bonds, $M_{i,t}$ is i's end-of period nominal money holdings, r_t^k is the real return to inherited capital, $k_{i,t-1}$, $D_{i,t}$ is i's nominal dividends paid by firms, W_t is the nominal wage rate, R_{t-1} is the gross nominal return to government bonds between $t-1$ and t, $T_{i,t}^l$ is nominal lump-sum taxes/transfers to each i from the government, and τ_t^c, τ_t^k, τ_t^n are respectively tax rates on private consumption, capital income and labour income.

[3] For the New Keynesian model, see the textbooks of Gali (2008) and Wickens (2008).

Dividing by P_t, the budget constraint of each i in real terms is:

$$\begin{aligned}(1+\tau_t^c)\,c_{i,t}+x_{i,t}+b_{i,t}+m_{i,t} &= \left(1-\tau_t^k\right)(r_t^k k_{i,t-1}+d_{i,t})+ \\ +(1-\tau_t^n)\,w_t n_{i,t}+R_{t-1}\tfrac{P_{t-1}}{P_t}b_{i,t-1}&+\tfrac{P_{t-1}}{P_t}m_{i,t-1}-\tau_{i,t}^l\end{aligned} \tag{4}$$

where small letters denote real variables, i.e. $m_{i,t} \equiv \frac{M_{i,t}}{P_t}$, $b_{i,t} \equiv \frac{B_{i,t}}{P_t}$, $w_t \equiv \frac{W_t}{P_t}$, $d_{i,t} \equiv \frac{D_{i,t}}{P_t}$, $\tau_{i,t}^l \equiv \frac{T_{i,t}^l}{P_t}$, at individual level.

The motion of physical capital for each household i is:

$$k_{i,t}=(1-\delta)k_{i,t-1}+x_{i,t} \tag{5}$$

where $0<\delta<1$ is the depreciation rate of capital.

Household i's consumption bundle at t, $c_{i,t}$, is a composite of $h=1,2,...,N$ varieties of goods, denoted as $c_{i,t}(h)$, where each variety h is produced monopolistically by one firm h. Using a Dixit-Stiglitz aggregator, we define:

$$c_{i,t}=\left[\sum_{h=1}^{N}\lambda[c_{i,t}(h)]^{\frac{\phi-1}{\phi}}\right]^{\frac{\phi}{\phi-1}} \tag{6}$$

where $\phi>0$ is the elasticity of substitution across goods produced and $\sum\limits_{h=1}^{N}\lambda=1$ are weights (to avoid scale effects, we assume $\lambda=1/N$).

Household i's total consumption expenditure is:

$$P_t c_{i,t}=\sum_{h=1}^{N}\lambda P_t(h)c_{i,t}(h) \tag{7}$$

where $P_t(h)$ is the price of variety h.

2.1.2 Household's optimality conditions

Each household i acts competitively taking prices and policy as given. Following the literature, to solve the household's problem, we follow a two-step procedure. Thus, we first suppose that the household chooses its desired consumption of the composite good, $c_{i,t}$, and, in turn, chooses how to distribute its purchases of individual varieties, $c_{i,t}(h)$. Details are available upon request. Then, the first-order conditions include the budget constraint above and:

$$\frac{c_{i,t}^{-\sigma}}{(1+\tau_t^c)}=\beta E_t\frac{c_{i,t+1}^{-\sigma}}{(1+\tau_{t+1}^c)}\left[\left(1-\tau_{t+1}^k\right)r_{t+1}^k+(1-\delta)\right] \tag{8}$$

$$\frac{c_{i.t}^{-\sigma}}{(1+\tau_t^c)} = \beta E_t \frac{c_{i,t+1}^{-\sigma}}{(1+\tau_{t+1}^c)} R_t \frac{P_t}{P_{t+1}} \tag{9}$$

$$\chi_m m_{i,t}^{-\mu} - \frac{c_{i,t}^{-\sigma}}{(1+\tau_t^c)} + \beta E_t \frac{c_{i,t+1}^{-\sigma}}{(1+\tau_{t+1}^c)} \frac{P_t}{P_{t+1}} = 0 \tag{10}$$

$$\chi_n \frac{n_{i,t}^{\eta}}{c_{i,t}^{-\sigma}} = \frac{(1-\tau_t^n)}{(1+\tau_t^c)} w_t \tag{11}$$

$$c_{i,t}(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} c_{i,t} \tag{12}$$

Equations (8) and (9) are respectively the Euler equations for capital and bonds, (10) is the optimality condition for money balances, (11) is the optimality condition for work hours and (12) shows the optimal demand for each variety of goods.

2.1.3 Implications for price bundles

Equations (7) and (12) imply that the general price index is (see also e.g. Wickens, 2008, chapter 7):

$$P_t = \left[\sum_{h=1}^{N} \lambda [P_t(h)]^{1-\phi}\right]^{\frac{1}{1-\phi}} \tag{13}$$

2.2 Firms

There are $h = 1, 2, ..., .N$ firms. Each firm h produces a differentiated good of variety h under monopolistic competition facing Calvo-type nominal fixities.

2.2.1 Demand for firm's product

Each firm h faces demand for its product, $y_t\,(h)$, coming from households' consumption and investment, $c_t(h)$ and $x_t(h)$, where $c_t(h) \equiv \sum_{i=1}^{N} c_{i,t}(h)$ and $x_t(h) \equiv \sum_{i=1}^{N} x_{i,t}(h)$, and from the government, $g_t\,(h)$. Thus, the demand for each firm's product is:

$$y_t\,(h) = c_t(h) + x_t(h) + g_t\,(h) \tag{14}$$

where from above:

$$c_t(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} c_t \tag{15}$$

and similarly:

$$x_t(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} x_t \tag{16}$$

$$g_t(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} g_t \tag{17}$$

where $c_t \equiv \sum_{i=1}^{N} c_{i,t}$, $x_t \equiv \sum_{i=1}^{N} x_{i,t}$ and g_t is public spending.

Since, at the economy level:

$$y_t = c_t + x_t + g_t \tag{18}$$

the above equations imply that the demand for each firm's product is:

$$y_t(h) = c_t(h) + x_t(h) + g_t(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} y_t \tag{19}$$

2.2.2 Firm's problem

Each firm h maximizes nominal profits, $D_t(h)$, defined as:

$$D_t(h) = P_t(h)y_t(h) - P_t r_t^k k_{t-1}(h) - W_t n_t(h) \tag{20}$$

All firms use the same technology represented by the production function:

$$y_t(h) = A_t[k_{t-1}(h)]^{\alpha}[n_t(h)]^{1-\alpha} \tag{21}$$

where A_t is an exogenous stochastic TFP process whose motion is defined below.

Under imperfect competition, profit maximization is subject to:

$$y_t(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} y_t \tag{22}$$

In addition, following Calvo (1983), firms choose their prices facing a nominal fixity. In each period, firm h faces an exogenous probability θ of not being able to reset its price. A firm h, which is able to reset its price, chooses its price $P_t^{\#}(h)$ to maximize the sum of discounted expected nominal profits for the next k periods in which it may have to keep its price fixed.

2.2.3 Firm's optimality conditions

Following the related literature, to solve the firm's problem above, we follow a two-step procedure. We first solve a cost minimization problem, where each firm h minimizes its cost by choosing factor inputs given technology and prices. The solution will give a minimum nominal cost function, which is a function of factor prices and output produced by the firm. In turn, given this cost function, each firm, which is able to reset its price, solves a maximization problem by choosing its price. Details are available upon request.

The solution to the cost minimization problem gives the input demand functions:

$$w_t = mc_t(1-a)A_t[k_{t-1}(h)]^{\alpha}[n_t(h)]^{-\alpha} \tag{23}$$

$$r_t^k = mc_t a A_t[k_{t-1}(h)]^{\alpha-1}[n_t(h)]^{1-\alpha} \tag{24}$$

where $mc_t = \Psi_t'(.)$ is the marginal nominal cost with $\Psi_t(.)$ denoting the associated minimum nominal cost function for producing $y_t\,(h)$ at t.

Then, the firm chooses its price, $P_t^{\#}\,(h)$, to maximize nominal profits written as:

$$\max \sum_{k=0}^{\infty} (\theta)^k E_t\ \Xi_{t,t+k}\ D_{t+k}\,(h) = \sum_{k=0}^{\infty} (\theta)^k E_t\ \Xi_{t,t+k}\ \left\{P_t^{\#}\,(h)\,y_{t+k}\,(h) - \Psi_{t+k}\,(y_{t+k}\,(h))\right\}$$

where $\Xi_{t,t+k}$ is a discount factor taken as given by the firm and where $y_{t+k}\,(h) = \left[\frac{P_t^{\#}(h)}{P_{t+k}}\right]^{-\phi} y_{t+k}$.

The first-order condition gives:

$$\sum_{k=0}^{\infty} (\theta)^k E_t\Xi_{t,t+k}\left[\frac{P_t^{\#}\,(h)}{P_{t+k}}\right]^{-\phi} y_{t+k}\left\{P_t^{\#}\,(h) - \frac{\phi}{\phi-1}\Psi'_{t+k}\right\} = 0 \tag{25}$$

We transform the above equation by dividing with the aggregate price index, P_t:

$$\sum_{k=0}^{\infty} (\theta)^k E_t[\Xi_{t,t+k}\left[\frac{P_t^{\#}\,(h)}{P_{t+k}}\right]^{-\phi} y_{t+k}\left\{\frac{P_t^{\#}\,(h)}{P_t} - \frac{\phi}{\phi-1}mc_{t+k}\frac{P_{t+k}}{P_t}\right\}] = 0 \tag{26}$$

Therefore, the behaviour of each firm h is summarized by the above three conditions (23), (24) and (26).

Each firm h which can reset its price in period t solves an identical problem, so $P_t^{\#}(h) = P_t^{\#}$ is independent of h, and each firm h which cannot reset its price just sets its previous period price $P_t\,(h) = P_{t-1}\,(h)$. Then, it can be shown that the evolution of the aggregate price level is given by:

$$(P_t)^{1-\phi} = \theta\,(P_{t-1})^{1-\phi} + (1-\theta)\left(P_t^{\#}\right)^{1-\phi} \tag{27}$$

2.3 Government budget constraint

Government's within-period budget constraint is (in aggregate nominal terms):

$$\begin{aligned} B_t + M_t &= R_{t-1}B_{t-1} + M_{t-1} + P_t g_t - \\ &- \tau_t^c P_t c_t - \tau_t^k (r_t^k P_t k_{t-1} + D_t) - \tau_t^n W_t n_t - T_t^l \end{aligned} \tag{28}$$

where B_t is the end-of-period total domestic nominal public debt, M_t is the end-of-period total stock of money balances. We also have $c_t \equiv \sum_{i=1}^{N} c_{i,t}$, $k_{t-1} \equiv \sum_{i=1}^{N} k_{i,t-1}$, $D_t \equiv \sum_{i=1}^{N} D_{i,t}$, $n_t \equiv \sum_{i=1}^{N} n_{i,t}$, $B_{t-1} \equiv \sum_{i=1}^{N} B_{i,t-1}$ and $T_t^l \equiv \sum_{i=1}^{N} T_{i,t}^l$, and all other variables have been defined above. Also recall that the government allocates its total expenditure among product varieties h by solving an identical problem with household i, so that $g_t(h) = \left[\frac{P_t(h)}{P_t}\right]^{-\phi} g_t$. In each period, one of the fiscal policy instruments (τ_t^c, τ_t^k, τ_t^n, g_t, T_t^l, B_t) has to follow residually to satisfy the government budget constraint.

Dividing by P_t, the government budget constraint is rewritten in real terms as:

$$\begin{aligned} b_t + m_t &= R_{t-1}\tfrac{P_{t-1}}{P_t} b_{t-1} + \tfrac{P_{t-1}}{P_t} m_{t-1} + g_t - \\ &- \tau_t^c c_t - \tau_t^k (r_t^k k_{t-1} + d_t) - \tau_t^n w_t n_t - \tau_t^l \end{aligned} \tag{29}$$

where $b_t \equiv \frac{B_t}{P_t}$, $m_t \equiv \frac{M_t}{P_t}$, $d_t \equiv \frac{D_t}{P_t}$, $w_t \equiv \frac{W_t}{P_t}$ and $\tau_t^l \equiv \frac{T_t^l}{P_t}$.

2.4 Decentralized equilibrium (for any feasible policy)

We now combine the above to solve for a Decentralized Equilibrium (DE) for any feasible monetary and fiscal policy. In this DE, (i) all households maximize utility (ii) a fraction $(1-\theta)$ of firms maximize profits by choosing the identical price $P_t^{\#}$, while the rest, θ, set their previous period prices (iii) all constraints are satisfied and (iv) all markets clear (details are available upon request).

The DE can be summarized by the following equilibrium conditions (all quantities are in per capita terms):

$$\frac{c_t^{-\sigma}}{(1+\tau_t^c)} = \beta E_t \frac{{c_{t+1}}^{-\sigma}}{(1+\tau_{t+1}^c)} \left[\left(1-\tau_{t+1}^k\right) r_{t+1}^k + (1-\delta)\right] \tag{30}$$

$$c_t^{-\sigma} \frac{1}{(1+\tau_t^c)} = \beta E_t R_t \frac{c_{t+1}^{-\sigma}}{(1+\tau_{t+1}^c)} \frac{P_t}{P_{t+1}} \tag{31}$$

$$\chi_m m_t^{-\mu} - \frac{c_t^{-\sigma}}{(1+\tau_t^c)} + \beta E_t \frac{c_{t+1}^{-\sigma}}{(1+\tau_{t+1}^c)} \frac{P_t}{P_{t+1}} = 0 \tag{32}$$

$$\chi_n \frac{n_t^{\eta}}{c_t^{-\sigma}} = \frac{(1-\tau_t^n)}{(1+\tau_t^c)} w_t \tag{33}$$

$$k_t = (1-\delta)\, k_{t-1} + x_t \tag{34}$$

$$\sum_{k=0}^{\infty} \theta^k E_t \left\{ \Xi_{t,t+k} \left[\frac{P_t^{\#}}{P_{t+k}} \right]^{-\phi} y_{t+k} \left(\frac{P_t^{\#}}{P_t} - \frac{\phi}{\phi-1} mc_{t+k} \frac{P_{t+k}}{P_t} \right) \right\} = 0 \tag{35}$$

$$w_t = mc_t(1-a)\frac{y_t}{n_t} \tag{36}$$

$$r_t^k = mc_t a \frac{y_t}{k_t} \tag{37}$$

$$d_t = y_t - w_t n_t - r_t^k k_{t-1} \tag{38}$$

$$y_t = \frac{1}{\left(\frac{\widetilde{P}_t}{P_t}\right)^{-\phi}} A_t k_{t-1}^a n_t^{1-a} \tag{39}$$

$$b_t + m_t = R_{t-1} b_{t-1} \frac{P_{t-1}}{P_t} + m_{t-1} \frac{P_{t-1}}{P_t} + g_t - \tau_t^c c_t - \tau_t^n w_t n_t - \tau_t^k \left(r_t^k k_{t-1} + d_t \right) - \tau_t^l \tag{40}$$

$$y_t = c_t + x_t + g_t \tag{41}$$

$$(P_t)^{1-\phi} = \theta (P_{t-1})^{1-\phi} + (1-\theta) \left(P_t^{\#} \right)^{1-\phi} \tag{42}$$

$$(\widetilde{P}_t)^{-\phi} = \theta (\widetilde{P}_{t-1})^{-\phi} + (1-\theta) \left(P_t^{\#} \right)^{-\phi} \tag{43}$$

where $\widetilde{P}_t \equiv \left(\sum_{h=1}^{N} \left[P_t\,(h) \right]^{-\phi} \right)^{-\frac{1}{\phi}}$ and $\left(\frac{\widetilde{P}_t}{P_t}\right)^{-\phi}$ is a measure of price dispersion.

We thus have 14 equilibrium conditions for the DE. To solve the model, we need to specify the policy regime and thus classify policy instruments into endogenous and exogenous. Regarding the conduct of monetary policy, we assume that the nominal interest rate, R_t, is used as a policy instrument, while, regarding fiscal policy, we assume that the residually determined public financing policy instrument is the end-of-period public debt, b_t. Then, the 14 endogenous variables are $\{y_t,\ c_t,\ n_t,\ x_t,\ k_t,\ m_t,\ b_t,\ P_t,\ P_t^{\#},\ \widetilde{P}_t,\ w_t,\ mc_t,\ d_t,\ r_t^k\}_{t=0}^{\infty}$. This is given the independently set policy instruments, $\{R_t,\ \tau_t^c,\ \tau_t^k,\ \tau_t^n,\ g_t,\ \tau_t^l\}_{t=0}^{\infty}$, technology, $\{A_t\}_{t=0}^{\infty}$, and initial conditions for the state variables.

2.5 Decentralized equilibrium transformed (for any feasible policy)

Before we specify the motion of independently set policy instruments and exogenous stochastic variables, we rewrite the above equilibrium conditions, first, by using inflation rates rather than price levels, second, by writing the firm's optimality condition (35) in recursive form and, third, by introducing a new equation that helps us to compute expected discounted lifetime utility. Details for each step are available upon request.

2.5.1 Variables expressed in ratios

We define three new endogenous variables, which are the gross inflation rate $\Pi_t \equiv \frac{P_t}{P_{t-1}}$, the auxiliary variable $\Theta_t \equiv \frac{P_t^{\#}}{P_t}$, and the price dispersion index $\Delta_t \equiv \left[\frac{\widetilde{P}_t}{P_t}\right]^{-\phi}$. We also find it convenient to express the two exogenous fiscal spending policy instruments as ratios of GDP, $s_t^g \equiv \frac{g_t}{y_t}$ and $s_t^l \equiv \frac{\tau_t^l}{y_t}$.

Thus, from now on, we use Π_t, Θ_t, Δ_t, s_t^g, s_t^l instead of P_t, $P_t^{\#}$, $\widetilde{P}_t$, g_t, τ_t^l respectively.

2.5.2 Equation (35) expressed in recursive form

Following Schmitt-Grohé and Uribe (2007), we look for a recursive representation of (35):

$$\sum_{k=0}^{\infty} (\theta)^k E_t \; \Xi_{t,t+k} \left[\frac{P_t^{\#}}{P_{t+k}}\right]^{-\phi} y_{t+k} \left\{\frac{P_t^{\#}}{P_t} - \frac{\phi}{(\phi-1)} mc_{t+k} \frac{P_{t+k}}{P_t}\right\} = 0 \tag{44}$$

We define two auxiliary endogenous variables:

$$z_t^1 \equiv \sum_{k=0}^{\infty} (\theta)^k E_t \; \Xi_{t,t+k} \left[\frac{P_t^{\#}}{P_{t+k}}\right]^{-\phi} y_{t+k} \frac{P_t^{\#}}{P_t} \tag{45}$$

$$z_t^2 \equiv \sum_{k=0}^{\infty} (\theta)^k E_t \; \Xi_{t,t+k} \left[\frac{P_t^{\#}}{P_{t+k}}\right]^{-\phi} y_{t+k} mc_{t+k} \frac{P_{t+k}}{P_t} \tag{46}$$

Using these two auxiliary variables, z_t^1 and z_t^2, we come up with two new equations which enter the dynamic system and allow a recursive representation of (44). In particular, we can replace equilibrium equation (35) with:

$$z_t^1 = \frac{\phi}{(\phi-1)} z_t^2 \tag{47}$$

where:

$$z_t^1 = \Theta_t^{-\phi-1} y_t + \beta\theta E_t \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left(\frac{\Theta_t}{\Theta_{t+1}}\right)^{-\phi-1} \left(\frac{1}{\Pi_{t+1}}\right)^{-\phi} z_{t+1}^1 \tag{48}$$

$$z_t^2 = \Theta_t^{-\phi} y_t mc_t + \beta\theta E_t \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left(\frac{\Theta_t}{\Theta_{t+1}}\right)^{-\phi} \left(\frac{1}{\Pi_{t+1}}\right)^{1-\phi} z_{t+1}^2 \tag{49}$$

Thus, from now on, we use (47), (48) and (49) instead of (35).

2.5.3 Lifetime utility written as a first-order dynamic equation

To compute social welfare, we follow Schmitt-Grohé and Uribe (2007) by defining a new endogenous variable, V_t, whose motion is:

$$V_t = \frac{c_t^{1-\sigma}}{1-\sigma} - \chi_n \frac{n_t^{1+\phi}}{1+\phi} + \chi_m \frac{m_t^{1-\mu}}{1-\mu} + \chi_g \frac{(s_t^g y_t)^{1-\zeta}}{1-\zeta} + \beta E_t V_{t+1} \tag{50}$$

where V_t is the expected discounted lifetime utility of the household at any t.

Thus, from now on, we add equation (50) and the new variable V_t to the equilibrium system.

2.6 Policy rules

Following the related New Keynesian literature, we focus on simple rules meaning that the monetary and fiscal authorities react to a small number of easily observable macroeconomic indicators. In particular, we allow the nominal interest rate, R_t, to follow a rather standard Taylor rule meaning that it can react to inflation and the output gap, while we allow the non-lump sum spending-tax policy instruments, s_t^g, τ_t^c, τ_t^k, τ_t^n, to react to the public debt burden and the output gap. Finally, we allow all policy instruments to also have a stochastic part which captures unexpected discretionary changes in policy. In particular, following e.g. Schmitt-Grohé and Uribe (2007), we use policy rules of the form:

$$\log\left(\frac{R_t}{R}\right) = \phi_\pi \log\left(\frac{\Pi_t}{\Pi}\right) + \phi_y \log\left(\frac{y_t}{y}\right) + \nu_t^R \tag{51}$$

$$s_t^g - s^g = -\gamma_l^g (l_{t-1} - l) - \gamma_y^g (y_t - y) + \nu_t^g \tag{52}$$

$$\tau_t^c - \tau^c = \gamma_l^c (l_{t-1} - l) + \gamma_y^c (y_t - y) + \nu_t^c \tag{53}$$

$$\tau_t^k - \tau^k = \gamma_l^k (l_{t-1} - l) + \gamma_y^k (y_t - y) + \nu_t^k \tag{54}$$

$$\tau_t^n - \tau^n = \gamma_l^n (l_{t-1} - l) + \gamma_y^n (y_t - y) + \nu_t^n \tag{55}$$

where variables without time subscripts denote long-run values, ϕ_π, ϕ_y, γ_l^q, $\gamma_y^q \geq 0$, where $q_t \equiv (s_t^g,\ \tau_t^c,\ \tau_t^k,\ \tau_t^n)$, are feedback policy coefficients, $l_{t-1} \equiv \frac{R_{t-1}b_{t-1}}{y_{t-1}}$ denotes the inherited public debt burden as share of GDP and $\nu_t^R, \nu_t^g, \nu_t^c, \nu_t^k, \nu_t^n$ are exogenous stochastic variables (defined below).

2.7 Exogenous stochastic variables

We assume that all the exogenous stochastic variables follow AR(1) processes:

$$\log A_t = \left(1-\rho^A\right)\log\left(A\right) + \rho^A \log A_{t-1} + \varepsilon_t^A \tag{56}$$

$$\log \nu_t^R = \left(1-\rho^R\right)\log\left(\nu^R\right) + \rho^R \log \nu_{t-1}^R + \varepsilon_t^R \tag{57}$$

$$\log \nu_t^g = \left(1-\rho^g\right)\log\left(\nu^g\right) + \rho^g \log \nu_{t-1}^g + \varepsilon_t^g \tag{58}$$

$$\log \nu_t^c = \left(1-\rho^c\right)\log\left(\nu^c\right) + \rho^c \log \nu_{t-1}^c + \varepsilon_t^c \tag{59}$$

$$\log \nu_t^k = \left(1-\rho^k\right)\log\left(\nu^k\right) + \rho^k \log \nu_{t-1}^k + \varepsilon_t^k \tag{60}$$

$$\log \nu_t^n = \left(1-\rho^n\right)\log\left(\nu^n\right) + \rho^n \log \nu_{t-1}^n + \varepsilon_t^n \tag{61}$$

where $0 \leq \rho^i \leq 1$ are persistence parameters and $\varepsilon_t^i \sim N\left(0,\ \sigma_i^2\right)$ where $i = A, R, g, c, k, n$.

2.8 Summing up

Using all the above, the final non-linear stochastic equilbrium system is**:**

$$\frac{{c_t}^{-\sigma}}{(1+\tau_t^c)} = \beta E_t \frac{{c_{t+1}}^{-\sigma}}{(1+\tau_{t+1}^c)}\left[\left(1-\tau_{t+1}^k\right)r_{t+1}^k + (1-\delta)\right] \tag{62}$$

$$\frac{{c_t}^{-\sigma}}{R_t}\frac{1}{(1+\tau_t^c)} = \beta E_t \frac{{c_{t+1}}^{-\sigma}}{(1+\tau_{t+1}^c)}\frac{1}{\Pi_{t+1}} \tag{63}$$

$$\chi_m m_t^{-\mu} - \frac{c_t^{-\sigma}}{(1+\tau_t^c)} + \beta E_t \frac{c_{t+1}^{-\sigma}}{(1+\tau_{t+1}^c)}\frac{1}{\Pi_{t+1}} = 0 \tag{64}$$

$$\chi_n \frac{n_t^\eta}{c_t^{-\sigma}} = \frac{(1-\tau_t^n)}{(1+\tau_t^c)} w_t \tag{65}$$

$$k_t = (1-\delta)\, k_{t-1} + x_t \tag{66}$$

$$z_t^1 = \frac{\phi - 1}{\phi} z_t^2 \tag{67}$$

$$w_t = mc_t (1-a)\frac{y_t}{n_t} \tag{68}$$

$$r_t^k = mc_t a \frac{y_t}{k_{t-1}} \tag{69}$$

$$d_t = y_t - w_t n_t - r_t^k k_{t-1} \tag{70}$$

$$y_t = \frac{1}{\Delta_t} A_t k_{t-1}^a n_t^{1-a} \tag{71}$$

$$b_t + m_t = R_{t-1} b_{t-1} \frac{1}{\Pi_t} + m_{t-1} \frac{1}{\Pi_t} + s_t^g y_t - \tau_t^c c_t - \tau_t^n w_t n_t - \tau_t^k \left[r_t^k k_{t-1} + d_t \right] - \tau^l \tag{72}$$

$$y_t = c_t + x_t + s_t^g y_t \tag{73}$$

$$\Pi_t^{1-\phi} = \theta + (1-\theta) \left[\Theta_t \Pi_t \right]^{1-\phi} \tag{74}$$

$$\Delta_t = (1-\theta) \Theta_t^{-\phi} + \theta \Pi_t^{\phi} \Delta_{t-1} \tag{75}$$

$$z_t^1 = y_t mc_t \Theta_t^{-\phi-1} + \beta\theta E_t \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left(\frac{\Theta_t}{\Theta_{t+1}} \right)^{-\phi-1} \Pi_{t+1}^{\phi} z_{t+1}^1 \tag{76}$$

$$z_t^2 = \Theta_t^{-\phi} y_t + \beta\theta E_t \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left(\frac{\Theta_t}{\Theta_{t+1}} \right)^{-\phi} \Pi_{t+1}^{\phi-1} z_{t+1}^2 \tag{77}$$

$$V_t = \frac{c_t^{1-\sigma}}{1-\sigma} + \chi_m \frac{m_t^{1-\mu}}{1-\mu} - \chi_n \frac{n_t^{1+\phi}}{1+\phi} + \chi_g \frac{\left(s_t^g y_t\right)^{1-\zeta}}{1-\zeta} + \beta E_t V_{t+1} \tag{78}$$

$$\log\left(\frac{R_t}{R}\right) = \phi_\pi \log\left(\frac{\Pi_t}{\Pi}\right) + \phi_y \log\left(\frac{y_t}{y}\right) + \nu_t^R \tag{79}$$

$$s_t^g - s^g = -\gamma_l^g \left(l_{t-1} - l\right) - \gamma_y^g \left(y_t - y\right) + \nu_t^g \tag{80}$$

$$\tau_t^c - \tau^c = \gamma_l^c \left(l_{t-1} - l\right) + \gamma_y^c \left(y_t - y\right) + \nu_t^c \tag{81}$$

$$\tau_t^k - \tau^k = \gamma_l^k \left(l_{t-1} - l\right) + \gamma_y^k \left(y_t - y\right) + \nu_t^k \tag{82}$$

$$\tau_t^n - \tau^n = \gamma_l^n \left(l_{t-1} - l\right) + \gamma_y^n \left(y_t - y\right) + \nu_t^n \tag{83}$$

$$l_t \equiv \frac{R_t b_t}{y_t} \tag{84}$$

There are therefore 23 equations in 23 endogenous variables, $\{y_t,\ c_t,\ n_t,\ x_t,\ k_t,\ m_t,\ b_t,\ \Pi_t,\ \Theta_t,\ \Delta_t,\ w_t,\ mc_t,\ d_t,\ r_t^k,\ z_t^1,\ z_t^2,\ V_t,\ R_t,\ s_t^g,\ \tau_t^c,\ \tau_t^k,\ \tau_t^n,\ l_t\}_{t=0}^{\infty}$. Among them, there are 17 non-predetermined or jump variables, $\{y_t,\ c_t,\ n_t,\ x_t,\ \Pi_t,\ \Theta_t,\ w_t,\ mc_t,\ d_t,\ r_t^k,\ z_t^1,\ z_t^2,\ V_t,\ s_t^g,\ \tau_t^c,\ \tau_t^k,\ \tau_t^n\}_{t=0}^{\infty}$, and 6 predetermined or state variables, $\{R_t,\ k_t,\ b_t,\ m_t,\ \Delta_t,\ l_t\}_{t=0}^{\infty}$. This is given technology and policy shocks, $\{A_t, \nu_t^R, \nu_t^g, \nu_t^c, \nu_t^k, \nu_t^n\}_{t=0}^{\infty}$, and initial conditions for the state variables. To solve this first-order non-linear difference equation system, we will take a second-order approximation around its long-run solution (details are in section 4 below). We first need to solve for the long run.

3 Data, calibration and long-run solution

This section solves numerically for the long run of the above model economy by using data from the euro zone. Since money is neutral in the long-run, interest rate policy does not matter to the real economy in the long run. Also, since fiscal policy instruments react to deviations of macroeconomic indicators from their long-run values, feedback fiscal policy coefficients do not play any role in the long run.

3.1 Data and calibration

The data are from OECD Economic Outlook no. 89. The time unit is meant to be a quarter. Our parameter values are summarized in Table 1.

Table 1: Parameter values

Parameter	Value	Description
a	0.33	share of capital
β	0.9926	discount factor
μ	3.42	real money balances elasticity
δ	0.021	capital depreciation rate (quarterly)
ϕ	6	price elasticity of demand
η	1	Frisch labour supply elasticity
σ	1	elasticity of intertemporal substitution
ζ	1	elasticity of public consumption in utility
θ	2/3	share of firms which cannot reset their prices
χ_m	0.05	preference parameter for real money balances
χ_n	6	preference parameter for hours worked
χ_g	0.1	preference parameter for public good
ρ^A	0.8	serial correlation of TFP shock
ρ^R	0.85	serial correlation of monetary shock
ρ^g	0.87	serial correlation of spending shock
ρ^c	0.96	serial correlation of consumption tax shock
ρ^k	0.97	serial correlation of capital tax shock
ρ^n	0.94	serial correlation of labour tax shock
σ_A	0.0062	standard deviation of innovation to TFP shock
σ_R	0.005	standard deviation of innovation to monetary shock
σ_g	0.016	standard deviation of innovation to spending shock
σ_c	0.001	standard deviation of innovation to consumption tax shock
σ_k	0.003	standard deviation of innovation to capital tax shock
σ_n	0.0005	standard deviation of innovation to labour tax shock

The value of the rate of time preference, β, follows from $R = 1.0075$, which is the average gross nominal interest rate in the data, and from setting $\Pi = 1$ for the long-run gross inflation rate. The real money balances elasticity, μ, is taken from Pappa and Neiss (2005). The elasticity of intertemporal substitution, σ, the Frisch labour elasticity, η, and the price elasticity of demand, ϕ, are as in Andrès and Doménech (2006) and Gali (2008). Regarding the preference parameters in the utility function, χ_m is chosen so as to obtain a yearly steady-state value of real money balances as ratio of output equal to 1.97 (0.5) quarterly (annually), χ_n is chosen so as to obtain steady-state labour hours equal to 0.28, while χ_g is set at 0.1 which is a common valuation of public goods in related utility functions.

Concerning the exogenous stochastic variables, we start by setting $\rho^A = 0.8$ and $\sigma_A = 0.0062$ for the persistence parameter and the standard deviation respectively of TFP in equation (56), which are as in Andrès and Doménech (2006). Regarding the public spending and interest rate policy shocks in equations (58) and (57), we follow Bi et al. (2010) by setting $\rho^g = 0.87$ and $\rho^R = 0.85$ for their persistence parameters, and $\sigma_g = 0.016$ and $\sigma_R = 0.005$ for their standard deviations, respectively. Finally, we run OLS regressions for consumption, capital and labor tax rates using Euro-zone data from 2001-2010, which imply $\rho^c = 0.96$, $\rho^k = 0.97$ and $\rho^n = 0.94$ for the persistence parameters, and $\sigma_c = 0.001$, $\sigma_k = 0.003$ and $\sigma_n = 0.0005$ for the standard deviations in (59), (60) and (61) respectively.

The long-run values of the exogenous policy instruments, τ_t^c, τ_t^k, τ_t^n, s_t^g, s_t^l, b_t, are either set at their data averages, or are calibrated to deliver data-consistent steady-state values for the endogenous variables. In particular, τ^c, τ^k, τ^n are the averages of the effective tax rates in the data. We set lump-sum taxes, s^l, so as to get a value of 0.43 for the sum $-s^l + s^g$, when the public debt-to-output ratio is 3.4 quarterly (or 0.85 annually) as in the average data over the recent period 2008-2011. The long-run values of policy instruments are summarized in Table 2.

Table 2: Long-run values of policy instruments

R	τ^c	τ^k	τ^n	s^g	$s^l \equiv \frac{\tau^l}{y^H}$
1.0075	0.19	0.28	0.38	0.23	-0.20

3.2 Status quo long-run solution

Table 3 reports the long-run solution of the model economy presented in subsection 2.8, when we use the parameter values in Table 1 and the policy instruments in Table 2. For comparison with the actual economy, Table 3 also presents some key ratios in the data whenever available. The solution makes sense and the resulting great ratios are close to their values in the data. In the next sections, we will depart from this status quo long-run solution to study various policy experiments.

Table 3: Long-run solution and some data

Variables	Long-run solution	Variables	Long-run solution	Data
y	0.74	d	0.12	-
c	0.46	r^k	0.04	-
n	0.28	z^1	1.82	-
x	0.11	z^2	2.18	-
k	5.19	V	-161.62	-
m	1.46	l	3.43	-
b	2.52	$\frac{c}{y}$	0.62	0.57
Π	1	$\frac{b}{y}$	3.4	3.4
Θ	1	$\frac{x}{y}$	0.15	0.18
Δ	1	$\frac{m}{y}$	1.97	-
w	1.47	$\frac{k}{y}$	7	
mc	0.83			

4 How we work

The aim of the paper is to study the implications of alternative policy rules for macroeconomic outcomes and lifetime utility. To make the comparison of alternative policies meaningful, we study optimal policy so that outcomes do not depend on ad hoc differences in the policy rules compared. As said, the welfare objective is household's expected lifetime utility.

We will study two economic environments. In the first (see section 5), the role of ecocomic policy is to stabilize the economy against temporary shocks as defined in subsection 2.7. This means that we depart from, and end up, at the same steady state as solved above. In the second environment (see section 6), the role of policy is twofold: to stabilize the economy against the same shocks as before and to improve resource allocation by gradually reducing the public debt ratio over time. Thus, in section 6, the transition dynamics will be driven, not only by shocks, but also by the difference between the initial pre-reformed steady state and the new reformed steady state (see also Cantore et al., 2012).

The reason we study two different economic environments (sections 5 and 6) is that we want to see whether the welfare ranking of alternative policy rules changes when we move to a richer setup with a more ambitious policy as that in section 6. Also, within each economic environment, we will study optimal policy under relatively low and relatively high extrinsic uncertainty as measured by the standard deviation of the exogenous stochastic variables.

Irrespectively of the policy experiments chosen, we need to compute optimized policy rules and choose a criterion to welfare rank alternative policies. These are explained in what follows in the rest of this section.

4.1 How we compute optimized policy rules and the equilbrium

We work in two steps. In the first step, we search for the ranges of feedback policy coefficients as defined in (51-55) which allow us to get a locally determinate decentralized equilibrium (this is what Schmitt-Grohé and Uribe, 2007, call implementable rules). If necessary, these ranges will be further restricted so as to give meaningful solutions for the policy instruments (e.g. capital tax rates less than one). In this search for local determinacy, we experiment with one, or more, policy instruments and one, or more, operating targets at a time.

In the second step, within the determinacy ranges found above, we compute the welfare-maximizing values of feedback policy coefficients (this is what Schmitt-Grohé and Uribe, 2005 and 2007, call optimized policy rules). The welfare criterion is to maximize the conditional welfare, V_0, as defined in (50) above or equivalently (85) below, where conditionality refers to the initial conditions chosen; the latter are given by the status quo long-run solution. To this end, following e.g. Schmitt-Grohé and Uribe (2004), we take a second-order approximation to both the equilibrium conditions and the welfare criterion. As is well known, this is consistent with risk-averse behavior on the part of economic agents and can also help us to avoid possible spurious welfare results that may arise when one takes a second-order approximation to the welfare criterion combined with a first-order approximation to the equilibrium conditions (see e.g. Gali, 2008, pp. 110-111, Malley et al., 2009, and, for a recent review, Benigno and Woodford, 2012).

In other words, we compute the feedback policy coefficients so as to maximize the second-order approximation of conditional welfare subject to the second-order appoximation of the decentralized equilibrium when the feedback policy coefficients are restricted to be within prespecified ranges delivering determinacy.

4.2 How we welfare rank alternative regimes

To welfare rank alternative policy regimes, we need to evaluate their welfare gains, or losses, relative to a reference regime. We find it natural to define the latter as the case in which policy is passive, in the sense that all policy instruments are held constant and equal to their steady-state values which are as in the data averages.

Let V_t^s denote the value function under a stabilization regime s. Thus,

$$V_0^s \equiv E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t^s, n_t^s, m_t^s, g_t^s\right) \tag{85}$$

where c_t^s, n_t^s, m_t^s and g_t^s are the equilibrium values of consumption, hours worked, real money balances and public spending under regime s.

Let also V_t^r denote the value function under the reference or passive regime, r. Thus,

$$V_0^r \equiv E_0 \sum_{t=0}^{\infty} \beta^t U\left(c_t^r, n_t^r, m_t^r, g_t^r\right) \tag{86}$$

where c_t^r, n_t^r, m_t^r and g_t^r are the equilibrium values of consumption, hours worked, real money balances and public spending under passive policy.

Then, following most of the literature on policy reforms, we denote by ξ the permanent consumption subsidy that the household would need under the reference regime r so as to be as well off as under regime s. Using the model parameterization in Table 1 above, ξ is approximately given by:

$$\xi \simeq \left(V_0^s - V_0^r\right)(1-\beta) \tag{87}$$

so that if $\xi > 0$ (resp. $\xi < 0$), the agent is better off under s (resp. under r). The stabilization regime with the highest value of ξ will be the most preferred one.

5 Stabilization policy

We now study the implications of different policy rules when the economy is hit by the temporary shocks as defined in section 2.7 above. Thus, the government solves a stabilization problem only. Technically, this means that we depart from, and end up, at the same steady state as that found in section 3 above, so that transition dynamics are driven by shocks only. Recall that, along the transition path, nominal rigidities imply that money is not neutral, so that feedback interest-rate policy, as defined in equation (51), matters to the real economy. Also recall that, along the transition path, different feedback fiscal rules, as defined in equations (52)-(55), have different implications.

5.1 Results under relatively low uncertainty

We start with conditions for local determinacy. We report that economic policy guarantees determinacy when the nominal interest rate reacts to inflation aggressively with $\phi_\pi > 1$, that is, when the Taylor principle is satisfied, and, at the same time, the fiscal policy instruments, $q_t \equiv (s_t^g,\ \tau_t^c,\ \tau_t^k,\ \tau_t^n)$, react in general to public liabilities above a critical minimum value, $\gamma_l^q > \underline{\gamma}_l^q > 0$. By contrast, the values of ϕ_y and γ_y^q, measuring respectively the reaction of interest rate policy and fiscal policy to the output gap, are not found to be critical to determinacy. The regions of feedback policy coefficients that guarantee determinacy are reported in detail in the notes of Table 4.[4] Thus, the general message is that monetary and fiscal policy need to interact with each other in a specific way for policy to guarantee determinacy. Or, as Leeper (2010) puts it, there is a "dirty little secret": for monetary policy to control inflation, fiscal policy must behave in a particular manner.

5.1.1 Optimized policy rules

Within the determinacy areas, we now turn to optimized policy rules. Thus, as explained above, we search for those values of the feedback policy coefficients, and the indicators that the policy instruments respond to, that maximize household's conditional welfare in (50), when we allow monetary policy to react to inflation and output, and fiscal policy to react to public liabilities and output. To understand the logic of our results, and following usual practice, we start by examining one fiscal instrument at a time. Results are reported in Table 4. The values of ξ give the welfare gains vis-a-vis the benchmark case without stabilization policy, namely, when all feedback policy coefficients are exogenously set to zero.

The main results are as follows. First, in terms of fiscal policy, the best instrument to use is government spending. The next best choice is to use the consumption tax rate, in turn, capital and, lastly, the labour tax rate. Notice that use of the labor tax rate is distinctly the worst choice to make.

Second, the best policy mix is to use government spending to react to debt only and the nominal interest rate to react to inflation only. In this case, with our baseline parameterization, a welfare gain of 2.2% is achieved when the monetary and fiscal authorities jointly intervene to stabilize the economy against shocks.

[4] Actually, we can distinguish two regions of determinacy. In addition to the one discussed above, there is another region in which fiscal policy does not react to public liabilities, i.e. $\gamma_l^q = 0$ for all fiscal instruments, while monetary policy reacts to inflation mildly with $\phi_\pi < 1$. This region is welfare inferior to the region discussed above. It also contains some sub-areas where determinacy breaks down. Several other papers have distinguished betwen the same two areas of determinacy (e.g. Leeper, 1991, and Schmitt-Grohé and Uribe, 2007).

Third, in all cases, the monetary authority should react aggressively to inflation, $\phi_\pi = 3$, and the fiscal authorities should react to debt, $\gamma_l^q > 0$. This is consistent with the consensus assignment (see e.g. Kirsanova et al., 2009).

Fourth, policy reaction to the output gap is desirable, ϕ_y, $\gamma_y^q > 0$, only when we use taxes for debt stabilization. This applies to both monetary and fiscal policy. The idea is that changes in taxes hurt the real economy, so, at the same time, monetary and fiscal policy need to be concerned about the output gap; by contrast, this is not necessary when we use public spending for debt stabilization, hence $\phi_y = \gamma_y^g = 0$ in this case. Therefore, the desirability of output stabilization, or counter-cyclical policy, depends on which fiscal policy instrument is used for debt stabilization. Notice the strong reaction of the labor tax rate to the output gap, γ_y^n (see below for details).

Fifth, fiscal reaction to public debt should be mild, except from the case in which we use the capital tax rate as a debt stabilization device (see the high value of γ_l^k in Table 4). The intuition behind this relatively strong reaction is as follows. When we use the capital tax rate to react to debt imbalances in the short run, this works like a capital levy on existing wealth which is not so distorting. At the same time, debt stabilization in the short run implies a reduced fiscal burden and expectations of lower capital taxes in the future, which can in turn stimulate investment. This dynamic effect is consistent with the theoretical results of Chamley (1986) and Judd (1985) and the simulations of Altig et al. (2001) who study tax reforms in the US. This is why γ_l^k is high (at least, when extrinsic macroeconomic volatility is relatively low - see also below).

Table 4: Optimal monetary reaction to inflation and output
and optimal fiscal reaction to debt and output

Policy instruments	Optimal interest-rate reaction to inflation and output	Optimal fiscal reaction to debt and output	ξ
$R_t \quad s_t^g$	$\phi_\pi = 3$ $\phi_y = 0$	$\gamma_l^g = 0.1$ $\gamma_y^g = 0$	0.022
$R_t \quad \tau_t^c$	$\phi_\pi = 3$ $\phi_y = 0.096$	$\gamma_l^c = 0.1$ $\gamma_y^c = 0.3428$	0.0206
$R_t \quad \tau_t^k$	$\phi_\pi = 3$ $\phi_y = 0.39$	$\gamma_l^k = 3$ $\gamma_y^k = 0.051$	0.02
$R_t \quad \tau_t^n$	$\phi_\pi = 3$ $\phi_y = 0.044$	$\gamma_l^n = 0.1$ $\gamma_y^n = 3$	0.0195

Notes: When we use government spending, the ranges are $\phi_\pi \in [1.1, 3]$, $\phi_y \in [0, 3]$, $\gamma_l^g \in [0.1, 3]$ and $\gamma_y^g \in [0, 3]$. When we use consumption taxes, the ranges are $\phi_\pi \in [1.1, 3]$, $\phi_y \in [0, 3]$, $\gamma_l^c \in [0.1, 3]$ and $\gamma_y^c \in [0, 3]$. When we use capital taxes, the ranges are $\phi_\pi \in [1.25, 3]$, $\phi_y \in [0, 3]$, $\gamma_l^k \in [0, 3]$ and $\gamma_y^k \in$ [0,3]. When we use labor taxes, the ranges are $\phi_\pi \in [1.25, 3]$, $\phi_y \in [0, 3]$, $\gamma_l^n \in [0.1, 3]$ and $\gamma_y^n \in [0, 3]$.

In the above experiments, we switched on one fiscal instrument at a time. To further test our results, we now switch on all fiscal policy instruments at the same time. That is, the monetary authorities are free to use the nominal interest rate to react to both inflation and the output gap, while the fiscal authorities are allowed to use all spending-tax instruments simultaneously to react to both public liabilities and the output gap. We report that, in this case, the ranges of determinacy are much smaller than before when we used one fiscal instrument at a time. Nevertheless, despite this restriction, we report that our main results in Table 4 are not affected. Namely, the best mix is to use government spending to react to debt only and the nominal interest rate to react to inflation only.

5.1.2 Impulse response functions

We now present the impulse responce functions (IRFs) of some key endogenous variables when there is a negative TFP shock (with a relatively low standard deviation, 0.0062). As pointed out in the Introduction, since, in most cases, it is optimal for policy instruments to react to more than one indicator at the same time, the IRFs can show which reaction dominates.

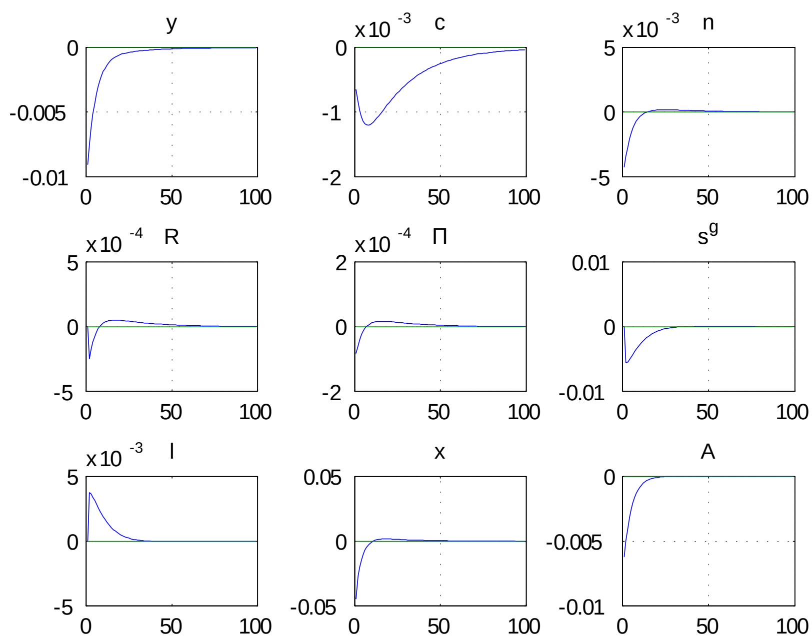
We start with the case in which we use the best possible policy mix (see Table 4, row 1). That is, we use the nominal interest rate to react to price inflation only and the public spending share to react to public debt only, with feedback coefficients $\phi_\pi = 3$ and $\gamma_l^g = 0.1$ respectively. All other policy feedback coefficients are set at zero, which means that τ_t^c, τ_t^k and τ_t^n remain constant at their steady-state values (data averages). Thus, we use the optimized policy rules:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) \tag{88}$$

$$s_t^g - s^g = -0.1 * (l_{t-1} - l) \tag{89}$$

which imply the IRFs shown in Figure 1.

Figure 1: Impulse responce functions to a negative TFP shock
under the best possible policy mix



As shown in Figure 1, an adverse TFP shock leads to a contraction in output, y, as expected. As a result, government liabilities as a ratio of output, l, rise. Under optimized rules, the fiscal authorities find it optimal to react to this rise in public liabilities by decreasing government spending, s^g. Notice that s^g decreases for several periods and returns back to its steady-state value only when l manages to fall. In the very short term, an adverse supply shock and the sharp fall in output lead to a fall in inflation, which is accompanied by a fall in the nominal interest rate via the optimized Taylor rule. But, very soon, the adverse supply shock leads to higher marginal costs and hence higher price inflation (this is a standard effect in the New Keynesian literature) which is now accompanied by a rise in the nominal interest rate again via the optimized Taylor rule. Higher inflation erodes the real value of government liabilities, l, which, jointly with the recovery of output, help the recovery in public spending in the medium run.

It is also interesting to present IRFs when, for some political-economy reason, policy is restricted to follow the sub-optimal policy mixes reported in Table 4, rows 2-4. The economy is hit by the same adverse TFP shock as above.

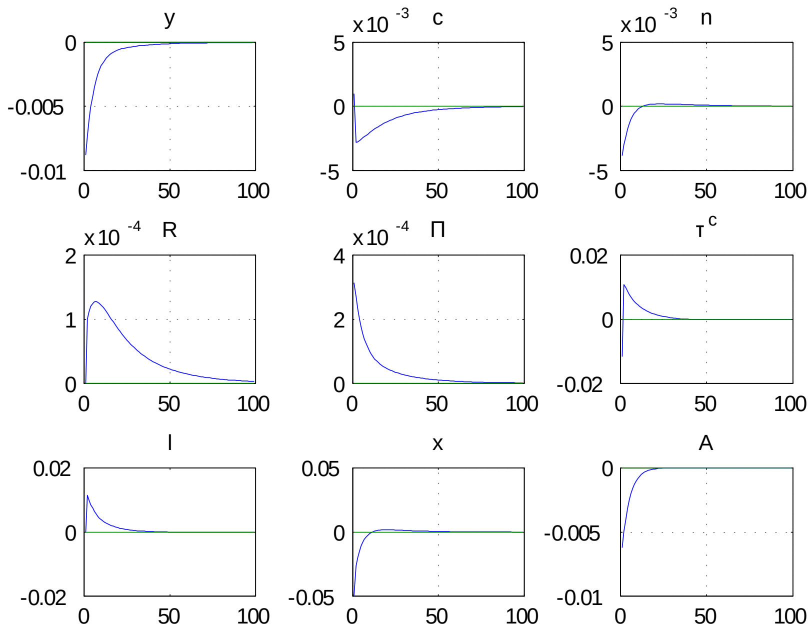
We start with the case in which the fiscal instrument is the consumption tax rate. This is the second row in Table 4. Thus, the optimized policy rules are:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.096 * \log\left(\frac{y_t}{y}\right) \tag{90}$$

$$\tau_t^c - \tau^c = 0.1 * (l_{t-1} - l) + 0.34 * (y_t - y) \tag{91}$$

which imply the IRFs shown in Figure 2. Before we discuss results, we present the IRFs for the other taxes too.

Figure 2: Impulse responce functions to a negative TFP shock
when the fiscal instrument is the consumption tax rate



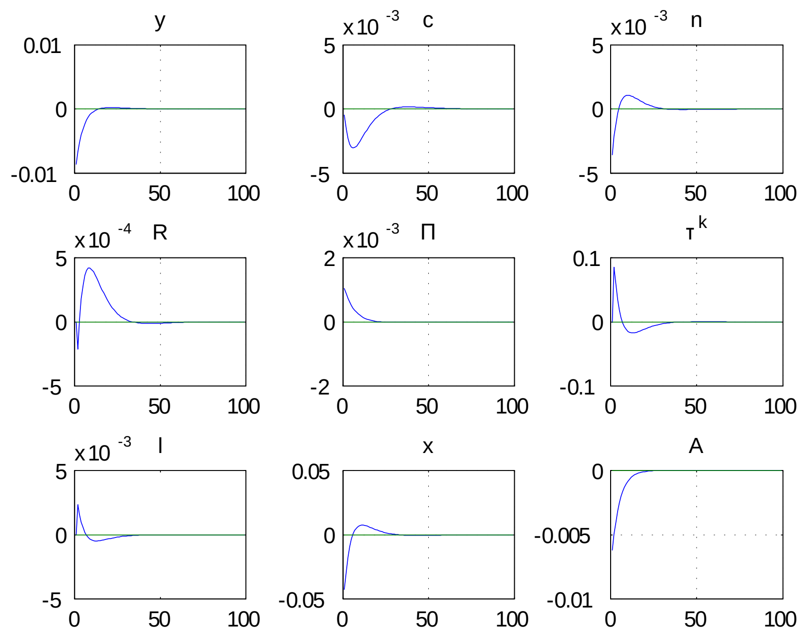
We continue with the case in which the fiscal instrument is the capital tax rate. This is the third row in Table 4. Thus, the optimized policy rules are:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.39 * \log\left(\frac{y_t}{y}\right) \tag{92}$$

$$\tau_t^k - \tau^k = 3 * (l_{t-1} - l) + 0.051 * (y_t - y) \tag{93}$$

which imply the IRFs shown in Figure 3.

Figure 3: Impulse responce functions to a negative TFP shock
when the fiscal instrument is the capital tax rate



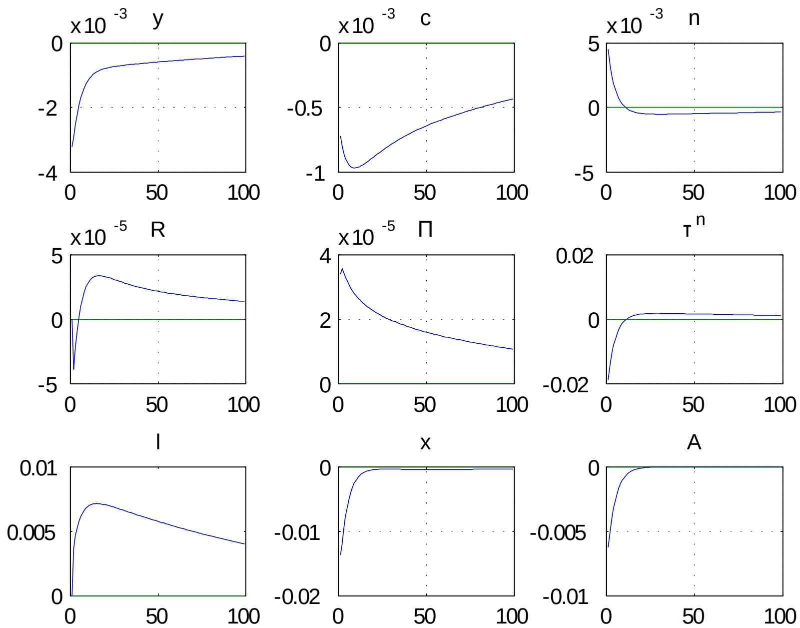
We finally study the case in which the fiscal instrument is the labor tax rate. This is the last row in Table 4. Thus, the optimized policy rules are:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.044 * \log\left(\frac{y_t}{y}\right) \tag{94}$$

$$\tau_t^n - \tau^n = 0.1 * (l_{t-1} - l) + 3 * (y_t - y) \tag{95}$$

which imply the IRFs shown in Figure 4.

Figure 4: Impulse responce functions to a negative TFP shock
when the fiscal instrument is the labour tax rate



Inspection of Figure 3 reveals that when the economy is hit by an adverse TFP shock, which results in an increase in the public debt ratio, the fiscal authorities find it optimal to increase capital tax rates at impact so as to stabilize the public debt ratio. By contrast, inspection of Figures 2 and 4 reveals that, in case they use consumption or labor tax rates, they find it optimal to reduce these tax rates, rather than increase them, at impact. This is at the expense of a long lasting rise in public debt. In particular, in the case of labor taxes, only when the effects of the adverse TFP shock fade away, the government starts increasing the labor tax rate to stabilize the debt dynamics.

Thus, in the case of consumption, and especially labor, taxes, the immediate priority should be given to output, rather than to debt. This is because a rise in consumption, and especially labor, taxes is particularly damaging to an economy hit by an adverse supply shock. By contrast, this is not the case with capital taxes. Capital taxes, if they are imposed in the very short run, they work as a tax on wealth, or a capital levy, so that they are less distorting than other taxes, especially since high capital taxes in the very short allow low capital taxes in the near future, the expectation of which can stimulate investment.

Summing up the evidence from IRFs in this subsection, when extrinsic uncertainty is relatively low and the only role of policy is to stabilize the economy against shocks, the policy priority should be given to the stabilization of debt cycles in case we use government spending and capital taxes. By contrast, when we use consumption and labor taxes, the policy priority should be given to the stabilization of output cycles. This is because consumption and labor taxes are more distorting than governent spending and capital levies, so we cannot afford to use them for debt imbalances when the economy is in a recession; instead, they should be spared to address the output cycle first and only, in turn, the debt cycle.

5.2 Results under relatively high uncertainty

So far, the best policy mix is to use public spending to react to public debt imbalances only, and the nominal interest rate to react to inflation only. We now check the robustness of this result, when we face a more volatile macroeconomic environment. In particular, other things equal, we arbitrarily increase the standard deviation of the TFP shock to 0.01 instead of 0.0062 that was used so far.

To save on space, we present the main results only and discuss what differs from the previous subsection which assumed relatively low macro volatility. We report that the policy coefficient regions required for determinacy remain the same as in Table 4 above.

5.2.1 Optimized policy rules

The new results are reported in Table 5. Comparison of Tables 5 and 4 implies that the main results remain unchanged. For instance, the welfare ranking of fiscal policy instruments does not change. Also, in all cases, interest rate policy should react aggressively to inflation and fiscal policy should react to debt imbalances. But there are also some new results. In Table 5, all values of γ_y^q, where $q_t \equiv (s_t^g, \tau_t^c, \tau_t^k, \tau_t^n)$, are positive. Thus, in a more volatile environment, fiscal reaction to the output gap is productive whatever fiscal policy instrument we choose to use. By contrast, recall that γ_y^g was zero in Table 4. Actually, in Table 5, fiscal reaction to the output gap should be stronger than fiscal reaction to public debt, i.e. $\gamma_l^q < \gamma_y^q$ in all cases. That is, in a more volatile environment, the fiscal priority should be given to the business cycle (this is confirmed below when we present impulse response functions).

Table 5: Optimal monetary reaction to inflation and output and optimal fiscal reaction to debt and output

Policy instruments	Optimal interest-rate reaction to inflation and output	Optimal fiscal reaction to debt and output	ξ
$R_t \quad s_t^g$	$\phi_\pi = 3$ $\phi_y = 0$	$\gamma_l^g = 0.1$ $\gamma_y^g = 0.11$	0.023
$R_t \quad \tau_t^c$	$\phi_\pi = 3$ $\phi_y = 0.055$	$\gamma_l^c = 0.1$ $\gamma_y^c = 0.28$	0.021
$R_t \quad \tau_t^k$	$\phi_\pi = 3$ $\phi_y = 0.22$	$\gamma_l^k = 1.34$ $\gamma_y^k = 3$	0.0202
$R_t \quad \tau_t^n$	$\phi_\pi = 3$ $\phi_y = 0.05$	$\gamma_l^n = 0.1$ $\gamma_y^n = 3$	0.0197

Notes: See the notes in Table 4 above.

5.2.2 Impulse response functions

As above, we present IRFs when the economy is hit by an adverse TFP shock. We start with the best possible policy mix in Table 5, row 1. Thus, the optimized rules for the nominal interest rate and the public spending share are:

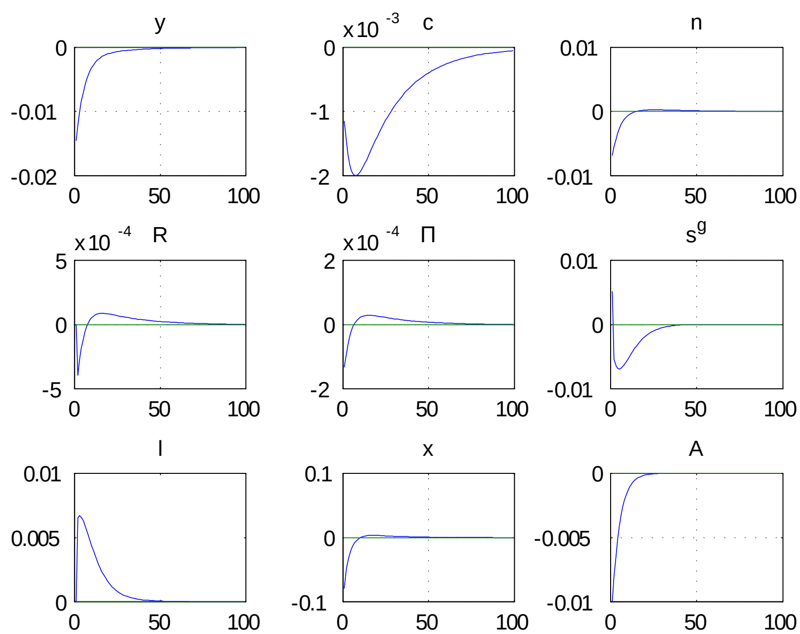
$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) \tag{96}$$

$$s_t^g - s^g = -0.1 * (l_{t-1} - l) - 0.11 * (y_t - y) \tag{97}$$

which imply the IRFs shown in Figure 5.

Figure 5: Impulse responce functions to a negative TFP shock

under the best possible policy mix



Before we discuss results, we also present IRFs under the suboptimal policy mixes in Table 5, rows 2-4. When the fiscal policy instrument is the consumption tax rate, we have the optimized rules:

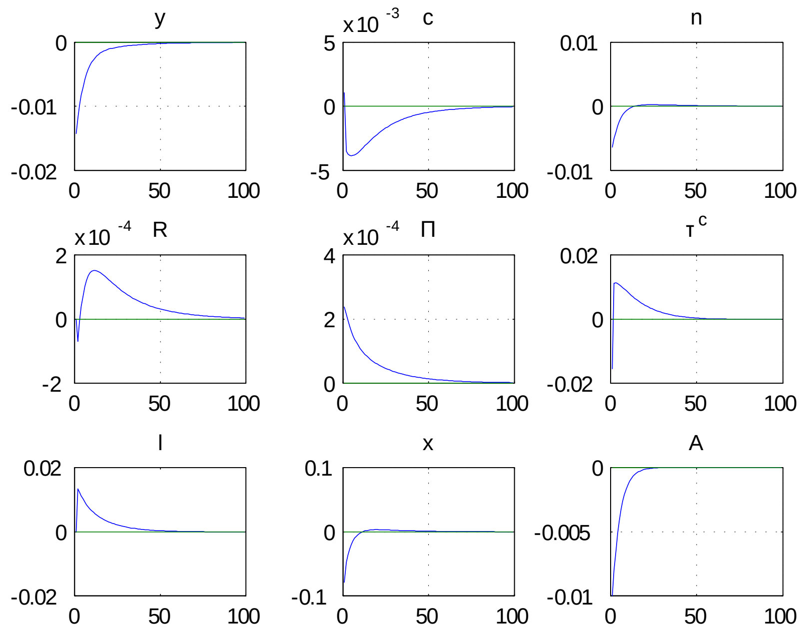
$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.055 * \log\left(\frac{y_t}{y}\right) \tag{98}$$

$$\tau_t^c - \tau^c = 0.1 * (l_{t-1} - l) + 0.28 * (y_t - y) \tag{99}$$

which imply the IRFs shown in Figure 6.

Figure 6: Impulse responce functions to a negative TFP shock

when the fiscal instrument is the consumption tax rate



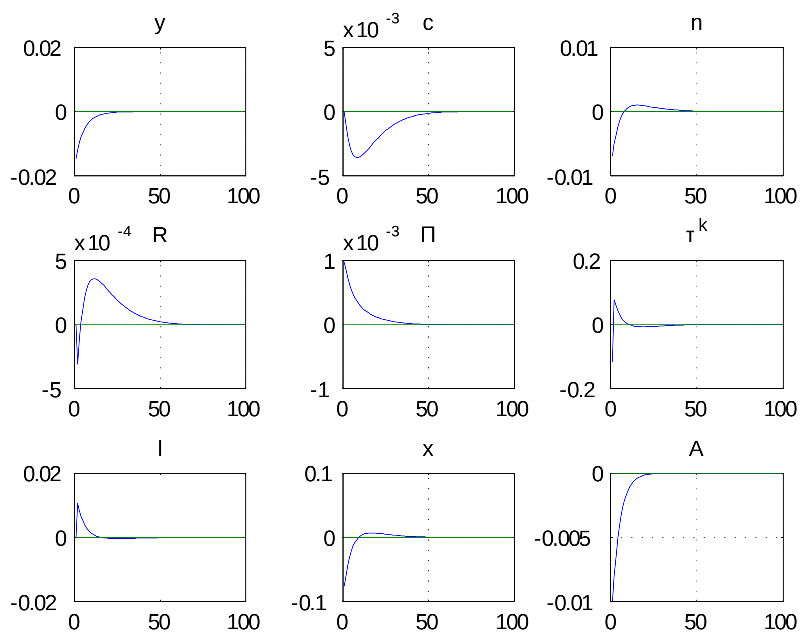
When the fiscal policy instrument is the capital tax rate, we have the optimized rules:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.22 * \log\left(\frac{y_t}{y}\right) \tag{100}$$

$$\tau_t^k - \tau^k = 1.34 * (l_{t-1} - l) + 3 * (y_t - y) \tag{101}$$

which imply the IRFs shown in Figure 7.

Figure 7: Impulse responce functions to a negative TFP shock
when the fiscal instrument is the capital tax rate



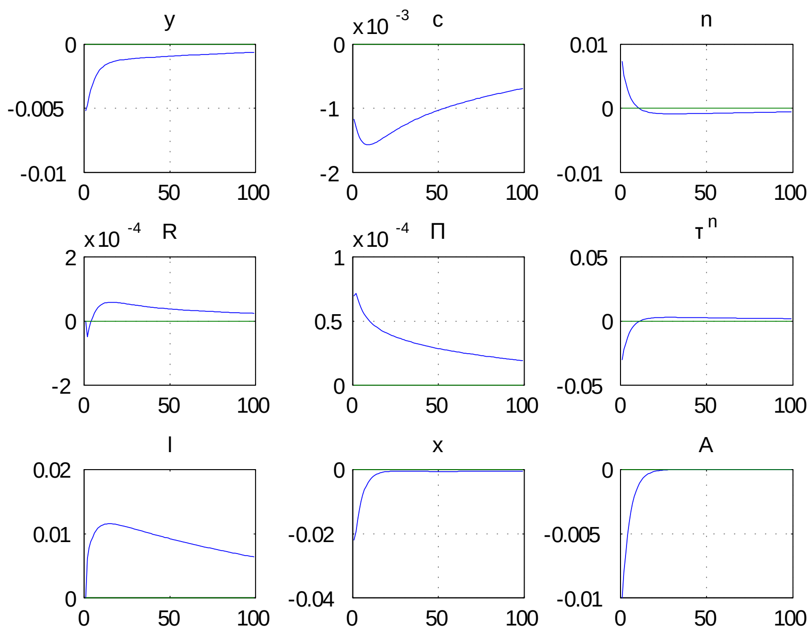
When the fiscal policy instrument is the labor tax rate, we have the optimized rules:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.05 * \log\left(\frac{y_t}{y}\right) \tag{102}$$

$$\tau_t^n - \tau^n = 0.1 * (l_{t-1} - l) + 3 * (y_t - y) \tag{103}$$

which imply the IRFs shown in Figure 8.

Figure 8: Impulse responce functions to a negative TFP shock
when the fiscal instrument is the labour tax rate



Figures 5-8 imply that public spending should rise, and tax rates should fall, at impact. In other words, when the economy is hit by a relatively strong adverse shock, the immediate reaction of fiscal authorities should be to counter the recession by following an expansionary fiscal policy and only in turn address debt imbalances. Therefore, the difference between Figures 1-4 and Figures 5-8 is that in the latter, which describe the case of relatively high uncertainty, all fiscal instruments should give priority to the business cycle in the short run, while, in the former, which described the case of relatively low uncertainty, this applied only to the more distorting policy instruments (consumption and labor taxes).

6 Stabilization and resource allocation policy together

We now study the implications of different policy rules when the economy is not only hit by temporary shocks as in the previous section but the government also wants to reduce the GDP share of public debt over time. In particular, we assume that the government reduces this share from 85% (which is its average value in the data over the last years - see section 3) to 60% (we choose the value of 60% simply because it is the reference rate of the Maastricht Treaty). Debt consolidation allows, other things equal, a cut in the tax rates, and a rise in public spending, in the long run, although this comes at the cost of higher taxes and lower public spending during the early phase of the transition path. Public financing issues, and how we model debt consolidation, are explained in the following subsection.

6.1 How we model debt consolidation

It is well recognized that the implications of fiscal reforms, like debt consolidation, depend heavily on the public financing policy instrument used, namely, which policy instrument adjusts endogenously to accommodate the exogenous changes in fiscal policy (see e.g. Leeper et al., 2010, and Leeper, 2010). Here, we will assume that, along the transition path, fiscal reforms are accommodated by adjustments in fiscal policy instruments, namely, the share of public spending, and the tax rates on capital income, labour income and consumption. To understand the logic of our results, and following usual practice in related studies, we will experiment with one fiscal instrument at a time. This means that, along the transition path, we allow one of the fiscal policy instruments to react to public debt imbalances, so as to stabilize debt around its new target value of 0.60 and, at the same time, the same fiscal policy instrument adjusts residually in the long run to close the government budget. Thus, the policy rules for these instruments are as in section 2.6 above except that now the targetted, or long-run, values are those of the reformed long-run equilibrium. All other fiscal policy instruments, except the one used for stabilization, remain unchanged and equal to the pre-reform steady-state values. The feedback policy coefficients of the fiscal policy instrument used for stabilization along the transition path, as well as the feedback policy coefficients of the nominal interest rate, are chosen optimally as explained in subsection 4.1 and as we did in the previous section.

In particular, we work as follows. We first solve and compare the long-run equilibria with and without debt consolidation. In turn, setting, as initial conditions for the state variables, their steady state solution of the economy without debt consolidation (see the status quo long-run solution in subsection 3.2), we compute the equilibrium transition path of each reformed economy under optimized policy rules and thus calculate the associated discounted lifetime utility of the household. This is for each method of public financing. This utility is finally compared to its associated value if there was no stabilization at all. Thus, the reference regime is the same as that used in the previous section so that welfare comparisons are easy to make. Recall that the model is stochastic so that now there are two sources of transitional dynamics: temporary shocks and the difference between the initial and the new reformed steady state.

6.2 Results under relatively low uncertainty

We report that the determinacy areas remain as above. Nevertheless, in the policy rule for the capital tax rate, we need to restrict the feedback coefficient on public debt in order to get a meaningful capital tax rate less than one, $\tau_t^k < 1$. In particular, the range is now narrower, $\gamma_l^k \in [0.1, 0.2]$, than it was before, $\gamma_l^k \in [0, 3]$. This can be explained by the Chamley-Judd result: when debt consolidation is among the policy aims, the fiscal authorities have an incentive to impose a high capital levy in the beginning of the time horizon to minimize the distortions during the rest of the transition period. The ranges of all feedback policy coefficients are summarized in the notes of Table 6.

6.2.1 Optimized policy rules

The new results are reported in Table 6. Comparison of Table 6 to Tables 5 and 4 above implies that again the main results remain unchanged. For instance, the welfare ranking of fiscal policy instruments does not change. Also, in all cases, interest rate policy should react aggressively to inflation and fiscal policy should react to debt imbalances. But there are also some new results. The welfare gains from policy intervention are higher than in Tables 4 and 5 above except in the case of labor taxes. That is, other things equal, reducing the public debt, in addition to stabilizing the economy against shocks, is welfare improving except when we have to use a particularly distorting policy instrument like labor taxes. Also notice, in Table 6, that reaction to the output gap is recommended to both the fiscal and monetary authorities when they use the best possible mix, R_t and s_t^g. The idea is that the effort to reduce public debt over time hurts the real economy, so, at the same time, monetary and fiscal policy need to be concerned about the output gap; by contrast, this was not necessary when the concern of policy was stabilization of shocks only (see Tables 4 and 5 above).

Table 6: Optimal monetary reaction to inflation and output and optimal fiscal reaction to debt and output

Policy instruments	Optimal interest-rate reaction to inflation	Optimal fiscal reaction to debt and output	ξ[5]
$R_t \quad s_t^g$	$\phi_\pi = 3$ $\phi_y = 0.15$	$\gamma_l^g = 0.1$ $\gamma_y^g = 0.17$	0.0245
$R_t \quad \tau_t^c$	$\phi_\pi = 3$ $\phi_y = 0.14$	$\gamma_l^c = 0.16$ $\gamma_y^c = 0.34$	0.023
$R_t \quad \tau_t^k$	$\phi_\pi = 3$ $\phi_y = 0.49$	$\gamma_l^k = 0.2$[6] $\gamma_y^k = 0$	0.0229
$R_t \quad \tau_t^n$	$\phi_\pi = 3$ $\phi_y = 0.14$	$\gamma_l^n = 0.1$ $\gamma_y^n = 3$	0.0168

Notes: As in Table 4 except that now $\gamma_l^k \in [0.1, 0.2]$ in case we use capital taxes.

6.2.2 Impulse response functions

When we use the best policy mix in Table 6, row 1, the optimized policy rules are:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.15 * \log\left(\frac{y_t}{y}\right) \tag{104}$$

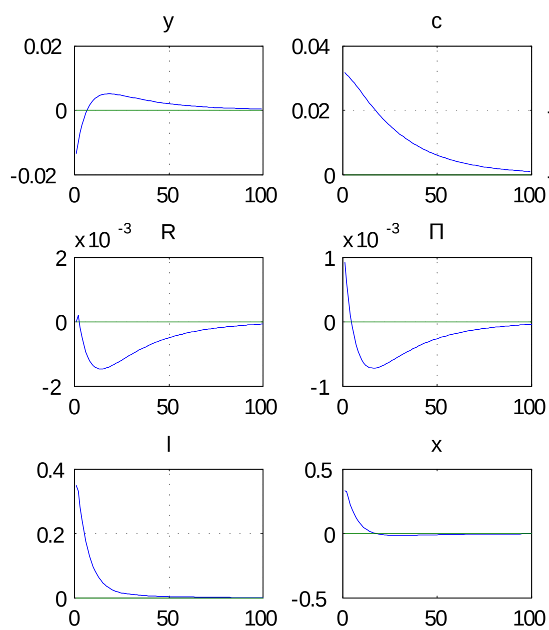
$$s_t^g - s^g = 0.1 * (l_{t-1} - l) + 0.17 * (y_t - y) \tag{105}$$

which imply the IRFs shown in Figure 9.

[5] In this case $\xi \simeq \left[\widehat{V}_0^s + V^s - \left(\widehat{V}_0^r + V^r\right)\right](1-\beta)$. Where the reference regime is the passive regime under low uncertainty.

[6] Due to feasibility reasons we restrict the value of the feedback policy coefficient associated with public debt to be $0.1 < \gamma_l^k < 0.2$.

Figure 9: Impulse responce functions to a negative TFP shock
under the best possible policy mix



Before we discuss results, we also present impulse response functions under the suboptimal policy mixes in Table 6, rows 2-4. When the fiscal policy instrument is the consumption tax rate, we have the optimized policy rules:

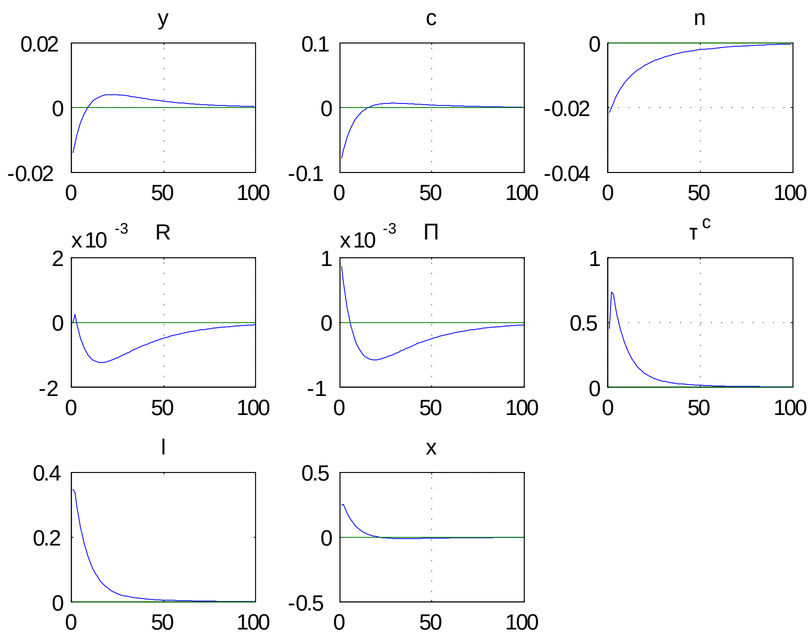
$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.14 * \log\left(\frac{y_t}{y}\right) \tag{106}$$

$$\tau_t^c - \tau^c = 0.14 * (l_{t-1} - l) + 0.34 * (y_t - y) \tag{107}$$

which imply the IRFs shown in Figure 10.

Figure 10: Impulse responce functions to a negative TFP shock

when the fiscal instrument is the consumption tax rate



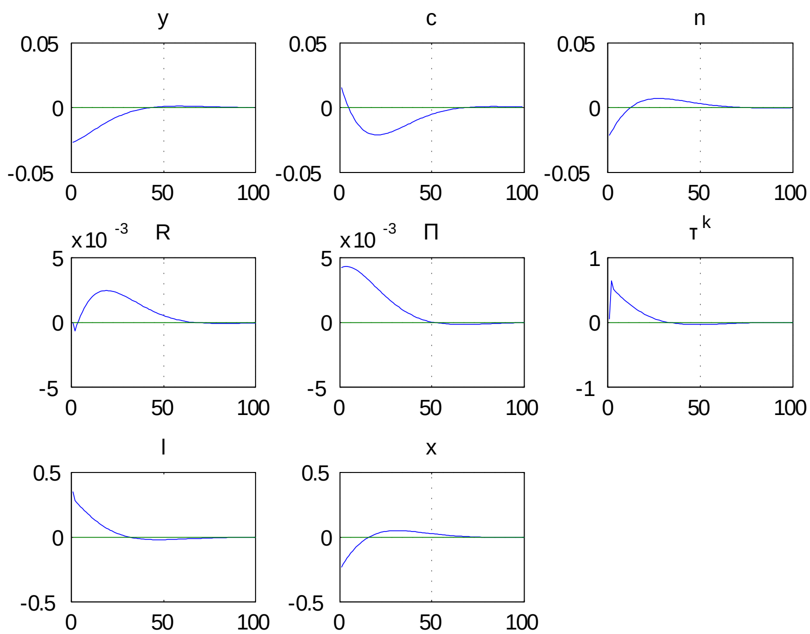
When the fiscal policy instrument is the capital tax rate, we have the optimized rules:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.49 * \log\left(\frac{y_t}{y}\right) \tag{108}$$

$$\tau_t^k - \tau^k = 0.2 * (l_{t-1} - l) \tag{109}$$

which imply the IRFs shown in Figure 11.

Figure 11: Impulse responce functions to a negative TFP shock when the fiscal instrument is the capital tax rate



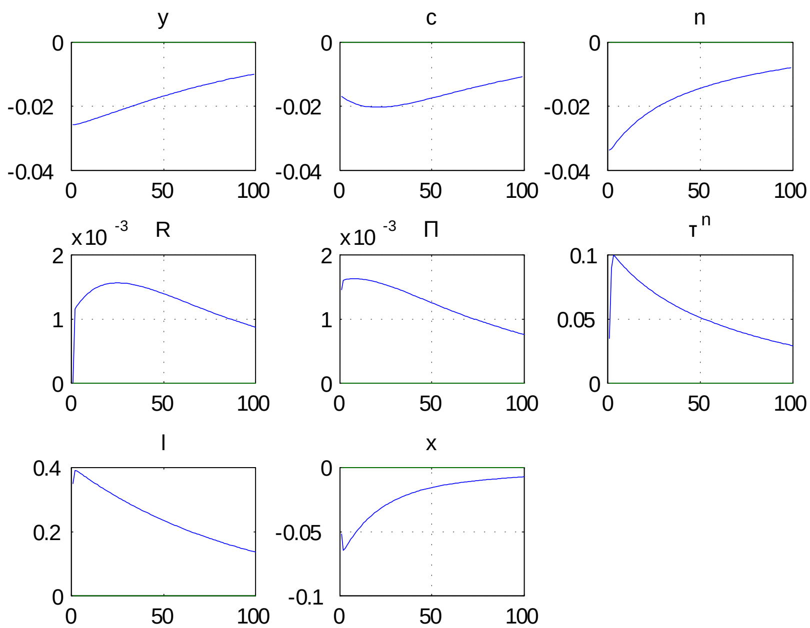
Finally, when the fiscal policy instrument is the labor tax rate, we have the optimized rules:

$$\log\left(\frac{R_t}{R}\right) = 3 * \log\left(\frac{\Pi_t}{\Pi}\right) + 0.14 * \log\left(\frac{y_t}{y}\right) \tag{110}$$

$$\tau_t^n - \tau^n = 0.1 * (l_{t-1} - l) + 3 * (y_t - y) \tag{111}$$

which imply the IRFs shown in Figure 12.

Figure 12: Impulse responce functions to a negative TFP shock when the fiscal instrument is the labour tax rate



Figures 9-12 imply that public spending should fall, and tax rates should rise. In other words, the concern for debt consolidation more than offsets the concern for shock stabilization even when the economy is hit an adverse shock. This is the opposite from Figures 5-8 above. In Figures 5-8, all fiscal instruments should give priority to the business cycle at impact, and only then should be used to address debt imbalances. By constrast, in Figures 9-12, all fiscal instruments should be earmarked for the reduction in public debt all the time.

Finally, inspection of the above IRFs implies that the duration of the debt consolidation phase, and so the speed of debt reduction, depend on which fiscal instrument we use. If we use the public spending ratio, s_t^g, it is optimal to reduce the debt ratio from 85% to 60% within 40 quarters, if we use consumption taxes, τ_t^c, within 50 quarters, if we use capital taxes, τ_t^k, within 40 quarters and, finally, if we use labor taxes, τ_t^n, in more than 100 quarters. Thus, the more distorting is the instrument used, the longer the period of adjustment should be.

6.3 Results under relatively high uncertainty

We report that, when we move to a more volatile economy as that defined in subsection 5.2, all qualitative results remain as in the previous subsection, 6.2. Thus, the results are driven by debt consolidation rather than by shock stabilization even in a more volatile environment.

7 Concluding remarks

This paper studied the optimal mix of monetary and fiscal policy actions in a New Keynesian model of a closed economy. The aim has been to welfare rank different fiscal (tax and spending) policy instruments when the central bank can follow a Taylor rule for the interest rate. We did so in two policy environments: first, when the policy task was to stabilize the economy against shocks and, second, when the government faced two tasks, shock stabilization and debt consolidation.

Since the results have been listed in the Introduction, we close with some extensions. First, it would be interesting to check the robustness of our results when we move to an open economy and in particular to an economy which is a member of a monetary union meaning that only fiscal policy can be used for national stabilization. Second, it would be interesting to study a two-country model, where the countries differ in the degree of fiscal imbalances and so in the size of debt reduction required. Finally, it would be interesting to add agent heterogeneity, in particular, to distinguish between private and public employees. The related literature has used representative agent models so issues of income and welfare distribution have not been studied. We leave these extensions for future work.

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