The optimal mix of monetary and fiscal policy

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Abstract

This paper studies optimized counter-cyclical monetary and fiscal policy rules. The setup is a conventional New Keynesian DSGE model. The model is calibrated to match data from the euro area. The aim is to welfare rank alternative tax-spending policy rules, when the monetary authorities follow a Taylor rule for the interest rate.

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1 Introduction

Policymakers use policy instruments to stabilize the economy. In normal times, central banks respond to inflation, the fiscal authorities to the state of public finances, and both of them to the level of economic activity. It is recognized 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, namely, the nominal interest rate, governments can make use of many types of spending and tax policy instruments. But different fiscal instruments behave differently both in terms of dynamic stability and effectiveness (see e.g. Coenen et al., 2012).

In this paper, we search for the best mix of monetary and fiscal policy actions when the economy is hit by productivity shocks. To do so, we welfare rank various fiscal policy instruments used for stabilization jointly with monetary policy. In particular, we specify rules for public spending, the tax rate on labor income, the tax rate on capital income and the tax rate on consumption that allow for response to a number of macroeconomic variables used as indicators, when, at the same time, monetary policy is also used in a Taylor-type fashion. We optimally choose both the indicators that the fiscal and monetary authorities react to, as well as the magnitude of feedback policy reaction to these indicators. 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.[2]

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 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. We first check determinacy. In particular, we search for

[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), Bi (2010) and Herz and Hohberger (2012). Schmitt-Grohé and Uribe (2007) allow total tax revenues to respond to public debt. But they do not welfare rank different fiscal policy instruments. 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. 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.

regions of policy reaction that prevent the emergence of multiple equilibria or instability. Determinacy requires that monetary policy reacts to price inflation satisfying the Taylor principle (meaning that the nominal interest rate reacts to inflation more than one-for-one) and fiscal policy reacts to the public debt burden, where the range of fiscal reaction to debt depends on the tax-spending policy instrument used. In other words, as Leeper (2010) points out, there is a "dirty little secret": for monetary policy to control inflation, fiscal policy must behave in a particular manner. To put it differently, some coordination between the central bank and the government is required by determinacy. Given this, reaction to the output gap, either by fiscal or by monetary policy, does not have drastic implications for determinacy.

Second, turning now to optimal policy, and within the determinacy areas specified above, the best policy mix is simple: government spending should react to public debt only and the nominal interest rate should react to price inflation only. In other words, concerning the choice of policy instruments, it is better to use government spending than tax rates for stabilization. Concerning the choice of indicators, it is not productive to react to the output gap, at least directly. This best policy mix provides support for the so-called "conventional assignment" of instruments to targets (see e.g. Kirsanova et al., 2009, and Leeper, 2010). Our computations imply that both responses (namely, the interest rate response to inflation and the public spending response to debt) should be mild in magnitude. The idea behind this policy mix is that when the government reduces public spending to stabilize the debt dynamics, and since the optimal response to debt is mild, this does not hurt the real economy (or it hurts it little relative to increasing the tax rates) and, as a result, response to the output gap is not nesessary. At the same time, without an output stabilization motive, the central bank does not need to take an aggressive anti-inflation stance either.

Third, when - for some political economy reason - policymakers are forced to use one of the tax instruments instead of public spending, the results get more complex although the logic remains the same. Concerning the choice of policy instruments, the welfare ranking varies but, in many cases, capital taxes appear to be superior to labor and consumption taxes. Concerning the choice of indicators, when we use (consumption, capital or labor) taxes to stabilize the debt dynamics, monetary policy should react to, not only inflation as above, but also the output gap. In particular, the interest rate should now react mildly to output and aggresively to inflation. The idea is that higher taxes hurt the real economy, so monetary policy needs to react also to the output gap. Actually, when we use capital or labor taxes, in particular, to stabilize the debt dynamics, it is rational that both monetary and fiscal authorities react also to the output gap, so as to mitigate the recessionary impact from higher distorting taxes to

the real economy. In other words, the desirability of counter-cyclical reaction to output, via interest rate management and/or fiscal policy, depends on which fiscal policy instrument is used for debt stabilization. At the same time, with an output stabilization motive, the central bank needs to take an aggressive anti-inflation stance.

Fourth, under the best policy mix, and if the economy is hit by an adverse productivity shock, our impulse response functions imply that, for a prolonged period, the government should cut public spending to stabilize the rise in public liabilities as a ratio of output. The very short-run reaction of the central bank is to cut the nominal interest rate, but, very soon, since an adverse productivity shock leads to higher marginal costs and hence higher inflation, the nominal interest rate has to rise.

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. The transition path and the main results of the paper are in section 4. Section 5 closes the paper.

2 The model

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

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.

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

The period utility function is assumed to be (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. Thus, σ is a coefficient of intertemporal subsititution and η is the Frisch labour elasticity.

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 received 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.

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

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

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 $\sum_{h=1}^{N} \lambda = 1$ 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:

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

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

$$\chi_m m_t^{-\mu} - \frac{c_t^{-\sigma}}{(1+\tau_t^c)} + \beta E_t \frac{c_{t+1}^{-\sigma}}{\left(1+\tau_{t+1}^c\right)} \frac{P_t}{P_{t+1}} = 0 \tag{10}$$

$$\chi_n \frac{n_t^{\eta}}{c_t^{-\sigma}} = \frac{(1-\tau_t^n)}{(1+\tau_t^c)} w_t \tag{11}$$

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

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:

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

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

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

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:

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

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.

Since the firm operates under imperfect competition, profit maximization is subject to the demand for its product, namely:

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

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 by 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 $P_t(h)=P_{t-1}(h)$. Thus, 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) firms of $(1-\theta)$ fraction maximize profits by choosing the identical price $P_t^{\#}$, while firms of θ fraction just set their previous period prices (iii) all constraints are satisfied and (iv) all markets clear (details are available upon request).

The DE is summarized by the following equilibrium conditions (all quantities are per capita):

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 variables 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.

Before we specify the independently set policy instruments and exogenous stochastic variables, we need to transform the above equilibrium conditions.

2.5 Decentralized equilibrium transformed (for any feasible policy)

In this section, following the related New Keynesian literature, we rewrite the above equilibrium conditions, first, by having inflation rates rather than price levels, secondly, by writing the firm's optimality conditions in recursive form and, thirdly, by introducing a new equation that helps us to compute lifetime utility. Algebraic details for each step are available upon request.

2.5.1 Variables expressed in ratios

We first express prices in rate form. In particular, 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 equation (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 denote 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, and equation (44), we come up with two new equations which enter the dynamic system and allow a recursive representation of (44). In particular, we 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

Since we want 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 like a value function in the sense that it is the expected discounted lifetime utility of the household at any t.

Thus, from now on, we add equation (50) 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 distorting 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. In particular, we use rules of the form:

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

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

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

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

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

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, and $l_{t-1} \equiv \frac{R_{t-1} b_{t-1}}{y_{t-1}}$ denotes the inherited public debt burden as share of GDP.

2.7 Exogenous stochastic variables

We assume that the TFP follows a stochastic AR(1) process:

$$A_t = A^{1-\rho} A_{t-1}^{\rho} e^{\varepsilon_t} \tag{56}$$

where $0 \leq \rho \leq 1$ is a parameter and $\varepsilon_t \sim N\left(0,\ \sigma_A^2\right)$.

2.8 Final equilibrium system

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

$$\frac{{c_t}^{-\sigma}}{(1+\tau_t^c)} = \beta E_t \frac{{c_{t+1}}^{-\sigma}}{\left(1+\tau_{t+1}^c\right)} \left[\left(1-\tau_{t+1}^k\right) r_{t+1}^k + (1-\delta)\right] \tag{57}$$

$$\frac{{c_t}^{-\sigma}}{R_t} \frac{1}{(1+\tau_t^c)} = \beta E_t \frac{{c_{t+1}}^{-\sigma}}{\left(1+\tau_{t+1}^c\right)} \frac{1}{\Pi_{t+1}} \tag{58}$$

$$\chi_m m_t^{-\mu} - \frac{c_t^{-\sigma}}{(1+\tau_t^c)} + \beta E_t \frac{c_{t+1}^{-\sigma}}{\left(1+\tau_{t+1}^c\right)} \frac{1}{\Pi_{t+1}} = 0 \tag{59}$$

$$\chi_n \frac{n_t^\eta}{c_t^{-\sigma}} = \frac{(1-\tau_t^n)}{(1+\tau_t^c)} w_t \tag{60}$$

$$k_t = (1-\delta)\, k_{t-1} + x_t \tag{61}$$

$$z_t^1 = \frac{\phi - 1}{\phi} z_t^2 \tag{62}$$

$$w_t = mc_t(1-a)\frac{y_t}{n_t} \tag{63}$$

$$r_t^k = mc_t a \frac{y_t}{k_{t-1}} \tag{64}$$

$$d_t = y_t - w_t n_t - r_t^k k_{t-1} \tag{65}$$

$$y_t = \frac{1}{\Delta_t} A_t k_{t-1}^a n_t^{1-a} \tag{66}$$

$$b_t + m_t = R_{t-1} b_{t-1} \frac{1}{\Pi_t} + m_{t-1} \frac{1}{\Pi_t} + s_t^g y_t - \tau_t^c c_t - \tau_t^n w_t n_t - \tau_t^k \left[r_t^k k_{t-1} + d_t\right] - \tau^l \tag{67}$$

$$y_t = c_t + x_t + s_t^g y_t \tag{68}$$

$$\Pi_t^{1-\phi} = \theta + (1-\theta)\left[\Theta_t \Pi_t\right]^{1-\phi} \tag{69}$$

$$\Delta_t = (1-\theta)\,\Theta_t^{-\phi} + \theta \Pi_t^\phi \Delta_{t-1} \tag{70}$$

$$z_t^1 = y_t mc_t \Theta_t^{-\phi-1} + \beta\theta E_t \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left(\frac{\Theta_t}{\Theta_{t+1}}\right)^{-\phi-1} \Pi_{t+1}^\phi z_{t+1}^1 \tag{71}$$

$$z_t^2 = \Theta_t^{-\phi} y_t + \beta\theta E_t \frac{c_{t+1}^{-\sigma}}{c_t^{-\sigma}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left(\frac{\Theta_t}{\Theta_{t+1}}\right)^{-\phi} \Pi_{t+1}^{\phi-1} z_{t+1}^2 \tag{72}$$

$$V_t = \frac{c_t^{1-\sigma}}{1-\sigma} + \chi_m \frac{m_t^{1-\mu}}{1-\mu} - \chi_n \frac{n_t^{1+\phi}}{1+\phi} + \chi_g \frac{\left(s_t^g y_t\right)^{1-\zeta}}{1-\zeta} + \beta E_t V_{t+1} \tag{73}$$

$$\log\left(\frac{R_t}{R}\right) = \phi_\pi \log\left(\frac{\Pi_t}{\Pi}\right) + \phi_y \log\left(\frac{y_t}{y}\right) \tag{74}$$

$$s_t^g = -\gamma_l^g \left(l_{t-1} - l\right) - \gamma_y^g \left(y_t - y\right) \tag{75}$$

$$\tau_t^c - \tau^c = \gamma_l^c \left(l_{t-1} - l\right) + \gamma_y^c \left(y_t - y\right) \tag{76}$$

$$\tau_t^k - \tau^k = \gamma_l^k \left(l_{t-1} - l\right) + \gamma_y^k \left(y_t - y\right) \tag{77}$$

$$\tau_t^n - \tau^n = \gamma_l^n \left(l_{t-1} - l\right) + \gamma_y^n \left(y_t - y\right) \tag{78}$$

$$l_t \equiv \frac{R_t b_t}{y_t} \tag{79}$$

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, $\{A_t\}_{t=0}^{\infty}$, 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 subsection 4.1 below). We first solve for the long run.

3 Data, calibration and long-run solution

This section calibrates the model to the euro area over 1995-2010 and then presents the long-run solution. Since money is neutral in the long-run, monetary policy does not matter to the real economy. Also, since fiscal policy instruments react to deviations of macroeconomic indicators from their long-run values, feedback fiscal policy coefficients also 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. Regarding parameters, we use conventional values used by related papers on the euro area (see

e.g. Pappa and Neiss, 2005, Andrés and Doménech, 2006, and Gali, 2008). 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
σ_A	0.0062	standard deviation of innovation to TFP shock

The value of the time preference rate, 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 taken from Andrès and Doménech (2006) and Gali (2008). Regarding preference parameters in the utility function, χ_m is chosen to obtain a yearly steady-state value of real money balances as ratio of output 1.98 (0.5) quarterly (annually), χ_n is chosen to obtain steady-state labour hours 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 set $\rho^A = 0.8$ and $\sigma_A = 0.0062$ for the persistence parameter and the standard deviation respectively of the TFP shock, which are as in Andrès and Doménech (2006).

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 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 2.88 (resp. 0.72) quarterly (resp. annually) as in the average data. 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 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.

Table 3: Long-run solution and some data

Variables	Long-run solution	Variables	Long-run solution	Data
y	0.74	mc	0.83	-
c	0.46	d	0.12	-
n	0.28	r^k	0.04	-
x	0.11	z^1	1.82	-
k	5.19	z^2	2.19	-
m	1.46	V	-161.62	-
b	2.11	l	2.88	-
Π	1	$\frac{c}{y}$	0.62	0.57
Θ	1	$\frac{b}{y}$	2.86	2.88
Δ	1	$\frac{x}{y}$	0.15	0.18
w	1.47	$\frac{m}{y}$	1.98	-

4 Transition, optimized policy rules and lifetime utility

We now study the transition path and the implications of different policy rules for macroeconomic outcomes and lifetime utility. Recall that, along the transition path, nominal rigidities imply that money is not neutral so that interest-rate policy matters to the real economy. Recall also that, along the transition path, different counter-cyclical fiscal rules have different implications.

We start by explaining how we work in the computational part of the paper.

4.1 How we compute the solution and the associated social welfare

Following e.g. Schmitt-Grohé and Uribe (2004, 2005 and 2007), we work in two steps. In the first step, we search for the ranges of feedback policy coefficients in (51-55) which allow us to get local determinacy under each policy regime studied (this is what Schmitt-Grohé and Uribe, 2007, call implementable rules). In our search for local determinacy, we experiment with one, or more, instruments and one, or more, operating targets at a time. In the second step, within the determinacy ranges found, 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 unconditional welfare, E_tV_t, as defined in (50) above. To this end, we take a second-order approximation to both the equilibrium conditions and the welfare criterion. As is 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, and, for a recent review, Benigno and Woodford, 2012). Computational details of the above are available upon request.

4.2 Numerical results

4.2.1 Regions of determinacy

As is expected, determinacy depends heavily on how policy instruments respond to targets. To study determinacy,[4] we begin with the standard case in which the nominal interest rate reacts to inflation only, while one of the fiscal instruments, $q_t \equiv (s_t^g,\ \tau_t^c,\ \tau_t^k,\ \tau_t^n)$, reacts to public liabilities only. That is, we switch on one fiscal instrument and one indicator at a time.

Policy can guarantee determinacy when monetary policy reacts to inflation with $\phi_\pi > 1$, in other words, when the Taylor principle is satisfied, while at least one of the fiscal policy instruments reacts to public liabilities above a critical minimum value, $\gamma_l^q > \underline{\gamma}_l^q > 0$. In particular, the critical minimum values, $\underline{\gamma}_l^q$, for public spending, consumption taxes, labor taxes and capital taxes are respectively $\underline{\gamma}_l^g = 0.01$, $\underline{\gamma}_l^c = 0.017$, $\underline{\gamma}_l^n = 0.021$ and $\underline{\gamma}_l^k = 0.024$. Thus, some degree of debt stabilization is always necessary for determinacy.[5]

[4] The regions of determinacy are taken up to first-order approximation.

[5] There is also determinacy when fiscal policy does not react to public liabilities, while monetary policy reacts to inflation with $\phi_\pi < 1$. We do not study this case because it is welfare inferior to the case mentioned above that

Counter-cyclical reaction to the output gap by using any of the fiscal instruments, $\gamma_y^q > 0$, does not affect the determinacy regions critically, as compared to the case in which these instruments react to public liabilities only. Counter-cyclical reaction to the output gap by using the nominal interest rate, $\phi_y > 0$, facilitates determinacy, in the sense that the higher the reaction to output, ϕ_y, the lower can be the reaction to inflation, ϕ_π. On the other hand, there is a complementarity between counter-cyclical monetary and fiscal reaction to output: the larger the fiscal reaction, γ_y^q, the larger the interest-rate reaction, ϕ_y, required for determinacy.

Within the above determinacy areas, we now turn to optimized policy rules. Thus, working as said in subsection 4.1 above, we search for the values of feedback policy coefficients, and the economic indicators that policy instruments respond to, that maximize the unconditional welfare in (50).

4.2.2 Optimal interest-rate responce to inflation and optimal fiscal response to public debt (one fiscal instrument at a time)

We begin with one fiscal instrument and one indicator at a time. In particular, fiscal policy instruments are allowed to react to public liabilities only, while, regarding monetary policy, the nominal interest rate is allowed to react to inflation only. This is the conventional assignment in the related literature (see e.g. Kirsanova et al., 2009, and Leeper, 2010). Results are reported in Table 4.

The highest welfare is achieved when we use government spending. The next best choice is to use the consumption tax rate, in turn, capital and, lastly, the labour tax rate. Two other results in Table 4 are also worth mentioning. Firstly, when we use government spending and consumption taxes, the optimal fiscal reaction is very close to the lowest possible value of the associated feedback policy coefficient required for determinacy. Thus, determinacy seems to be the priority in this case. Secondly, when the fiscal authority uses a tax instrument to react to public liabilities, it is optimal for the monetary authority to react aggressively to inflation, $\phi_\pi = 3$. By contrast, when the fiscal authority uses public spending to react to public liabilities, it is optimal for the monetary authority to react to inflation with the lowest possible value required for determinacy, $\phi_\pi = 1.1$. The intuition behind this behavior is discussed below.

satisfies the Taylor principle. Also, there is evidence that the ECB sets its nominal interest rate in a manner that satisfies the Taylor principle (see e.g. Kazanas et al., 2011, and the references therein).

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

Policy instruments	Optimal interest-rate reaction to inflation	Optimal fiscal reaction to debt	max $E_t\widehat{V}_t$
$R_t \quad s_t^g$	$\phi_\pi = 1.1$	$\gamma_l^g = 0.01$	0.066
$R_t \quad \tau_t^c$	$\phi_\pi = 3$	$\gamma_l^c = 0.0174$	0.0135
$R_t \quad \tau_t^k$	$\phi_\pi = 3$	$\gamma_l^k = 0.05$	0.011
$R_t \quad \tau_t^n$	$\phi_\pi = 3$	$\gamma_l^n = 0.04$	0.0109

4.2.3 Optimal interest-rate response to inflation and output and optimal fiscal response to public debt (one fiscal instrument at a time)

Now, the nominal interest rate is allowed to react to both inflation and the output gap, while fiscal policy reacts only to public liabilities, again with one fiscal instrument used at a time. Results are reported in Table 5. Comparison of Tables 4 and 5 reveals that the welfare ranking of fiscal instruments is unaffected by monetary policy reaction to the output gap. Notice, however, that the optimal monetary reaction to output is zero when we use public spending for debt stabilization, while it turns to positive when we use a tax instrument for debt stabilization. Thus, when we use a tax instrument to stabilize public debt, monetary reaction to the output gap results in higher welfare relative to Table 4 where monetary policy reacted to inflation only.

Therefore, the desirability of stabilizing output via interest rate management depends on which fiscal policy instrument is used for debt stabilization. Only when we use public spending for debt stabilization, direct counter-cyclical monetary policy is redundant. The intuition is as follows. When we reduce public spending to stabilize the dynamics of public debt, and given that the optimal reduction is mild, $\gamma_l^g = 0.01$, this is not recessionary, relatively speaking. By contrast, when we increase a tax instrument to stabilize the debt dynamics, this hurts economic activity, so, at the same time, a policy response to output is required to mitigate the recessionary implications of higher taxes. This logic can also explain why, in this case, the monetary authorities need to be more aggressive towards inflation (in Table 5, ϕ_π is 3 when we use taxes for debt stabilization, but only 1.1 when we use public spending). Namely, when we use taxes, and since a counter-cyclical monetary reaction to output is also desirable, we also need to be more concerned about inflation.

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

Policy instruments	Optimal interest-rate reaction to inflation and output	Optimal fiscal reaction to debt	max $E_t\widehat{V}_t$
$R_t \quad s_t^g$	$\phi_\pi = 1.1$ $\phi_y = 0$	$\gamma_l^g = 0.01$	0.066
$R_t \quad \tau_t^c$	$\phi_\pi = 3$ $\phi_y = 0.02$	$\gamma_l^c = 0.02$	0.0138
$R_t \quad \tau_t^k$	$\phi_\pi = 3$ $\phi_y = 0.034$	$\gamma_l^k = 0.03$	0.0137
$R_t \quad \tau_t^n$	$\phi_\pi = 3$ $\phi_y = 0.026$	$\gamma_l^n = 0.03$	0.0118

4.2.4 Optimal interest-rate response to inflation and optimal fiscal response to public debt and output (one fiscal instrument at a time)

Now fiscal policy can react to both public liabilities and the output gap with one instrument at a time, while monetary policy can react to inflation. Results are reported in Table 6. Public spending remains clearly the best fiscal instrument, although the ranking of taxes changes compared to Tables 4 and 5 above. In particular, capital and labour are now superior to consumption taxes. Notice also that the optimal responses of public spending and consumption taxes to the output gap are zero, while the analogous response of capital and labor taxes is positive meaning that now, ceteris paribus, it is optimal to reduce capital and labor taxes to react to a fall in economic activity. The intuition is as above. Namely, when we use capital and labor taxes to stabilize the debt dynamics, this is recessionary, so the fiscal authorities should be also concerned with the real economy; the combined optimal reaction to debt and output implies low capital and labor taxes relative to the case in Table 4 where the government was allowed to respond to debt only.

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

Policy instruments	Optimal interest-rate reaction to inflation	Optimal fiscal reaction to debt and output	max $E_t\widehat{V}_t$
$R_t \quad s_t^g$	$\phi_\pi = 1.1$	$\gamma_l^g = 0.01$ $\gamma_y^g = 0$	0.066
$R_t \quad \tau_t^c$	$\phi_\pi = 3$	$\gamma_l^c = 0.02$ $\gamma_y^c = 0$	0.0138
$R_t \quad \tau_t^k$	$\phi_\pi = 2.79$	$\gamma_l^k = 0.045$ $\gamma_y^k = 0.79$	0.02527
$R_t \quad \tau_t^n$	$\phi_\pi = 3$	$\gamma_l^n = 0.03$ $\gamma_y^n = 0.55$	0.01896

4.2.5 Optimal interest-rate response to inflation and output and optimal fiscal response to public debt and output (one fiscal instrument at a time)

We now allow monetary policy to react to both inflation and output, while fiscal policy can react to both public liabilities and output (again we study one fiscal instrument at a time). Results are reported in Table 7. Qualitatively, the picture is as in Table 6 above. That is, public spending clearly remains the best instrument to use, being followed by capital taxes, labor taxes and consumption taxes. Also, as in Table 6, public spending and consumption taxes do not need to react to the business cycle, while capital and labor taxes do (in order to mitigate their recessionary impact from using them to stabilize public debt). Moreover, as in Table 5, the interest rate does not need to be contingent on the business cycle when we use public spending for debt stabilization (because spending cuts hurt the real economy little), but it does when we use tax instruments for debt stabilization (because tax increases hurt the real economy) so the monetary authorities need to become more active.

Table 7: 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	max $E_t\widehat{V}_t$
$R_t \quad s_t^g$	$\phi_\pi = 1.1$ $\phi_y = 0$	$\gamma_l^g = 0.01$ $\gamma_y^g = 0$	0.066
$R_t \quad \tau_t^c$	$\phi_\pi = 3$ $\phi_y = 0.02$	$\gamma_l^c = 0.02$ $\gamma_y^c = 0$	0.0138
$R_t \quad \tau_t^k$	$\phi_\pi = 3$ $\phi_y = 0.023$	$\gamma_l^k = 0.05$ $\gamma_y^k = 1.144$	0.0274
$R_t \quad \tau_t^n$	$\phi_\pi = 3$ $\phi_y = 0.023$	$\gamma_l^n = 0.03$ $\gamma_y^n = 0.73$	0.0226

4.2.6 Using all policy instruments together

So far, in all experiments, the best fiscal policy instrument has been public spending. To further test this, we now switch on all policy instruments and all operating targets. Thus, the monetary authorities are free to use the nominal interest rate to react to both inflation and the output gap, while the fiscal authortites 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 where we used one fiscal instrument at a time. We also report that, in this case, using the fiscal instruments to react to the output gap does not deliver well-defined solutions; hence we set $\gamma_y^q = 0$ for all q. All other feedback policy coefficients, namely, ϕ_π, ϕ_y and γ_l^q, are switched on and are determined optimally. Results are reported in Table 8. Again, the message is that the best mix is to use government spending to react to debt only and the interest rate to react to inflation only.

Table 8: Optimal policy reaction to all indicators using all instruments together

Policy instruments	Reaction to inflation	Range	Optimal reaction	Reaction to output	Range	Optimal reaction
R_t	ϕ_π	[1.1, 3]	1.1	ϕ_y	[0, 0.1]	0
	Reaction to debt	Range	Optimal reaction	Reaction to output	Range	Optimal reaction
s_t^g	γ_l^g	[0.01, 0.1]	0.01	γ_y^g	[0, 0]	-
τ_t^c	γ_l^c	[0, 0.1]	0	γ_y^c	[0, 0]	-
τ_t^k	γ_l^k	[0, 0.1]	0	γ_y^k	[0, 0]	-
τ_t^n	γ_l^n	[0, 0.1]	0	γ_y^n	[0, 0]	-
Maximum (welfare gain) $E_t\widehat{V}_t = 0.066$						

4.2.7 IRFs under the best possible policy mix

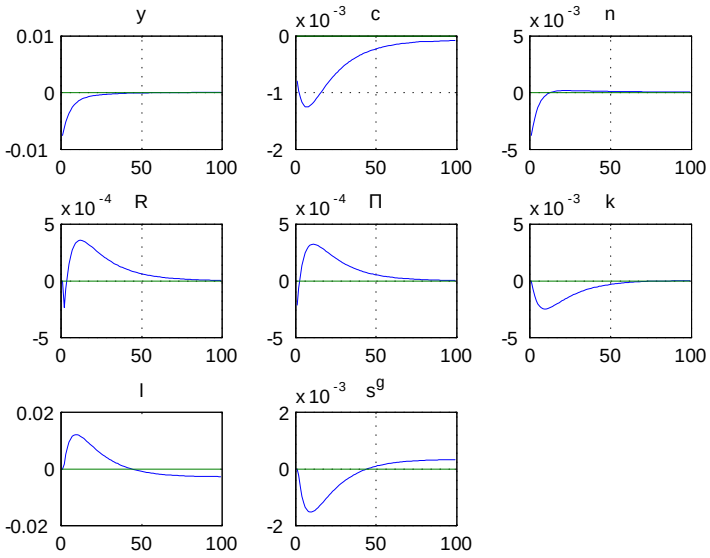
We now present the impulse responce functions of some key endogenous variables when there is a negative TFP shock (with standard deviation 0.0062) and when we use the best possible policy mix as found above. That is, we use the nominal interest rate to react to price inflation only and the public spending to GDP ratio to react to public debt only, with feedback coefficients $\phi_\pi = 1.1$ and $\gamma_l^g = 0.01$ respectively. All other policy feedback coefficients are set at zero, so that τ_t^c, τ_t^k and τ_t^n remain constant at their steady-state values (data averages).[6] Thus, we use the policy rules:

$$\log\left(\frac{R_t}{R}\right) = 1.1 * \log\left(\frac{\Pi_t}{\Pi}\right) \tag{80}$$

$$s_t^g - s^g = -0.01 * (l_{t-1} - l) \tag{81}$$

[6] Impulse response functions for other suboptimal policy mixes are available upon request.

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. Government liabilities as a ratio of output, l, rise for a long period. 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 increases only when l manages to fall below its steady-state value. 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. Note that higher inflation erodes the real value of government liabilities, l, which, jointly with the recovery of output, help the rise in public spending in the medium run.

5 Concluding remarks

This paper has studied the optimal mix of monetary and fiscal policy in a New Keynesian model of a closed economy hit by supply shocks. The aim has been to welfare rank different fiscal (tax and spending) policy instruments when the central bank can follow a Taylor rule.

Since the results are written in the Introduction, we close with some extensions. It would be interesting to add heterogeneity, in particular, in the form of distinguishing between private and public employees. The related literature has used representative agent models so issues of distribution have not been studied. It would also be interesting to use a two-country model, where the countries differ in the degree of fiscal imbalances. We leave these extensions for future work.

6 References

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