Credit Spreads and the Zero Bound on Interest Rates*

Isabel Correia[†], Fiorella De Fiore[‡], Pedro Teles[§] and Oreste Tristani[¶]

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Abstract

Nominal interest rates typically approach the zero-lower bound during a financial crisis. This is a constraint on optimal monetary policy: In a model with financial frictions, policy would set negative nominal interest rates in response to increases in credit spreads. We find that fiscal policy can mitigate the effect of the restriction imposed by the zero bound but cannot overcome it without incurring additional costs. The zero bound is a more severe constraint for policy due to inefficiencies in financial markets rather than to price rigidities.

Keywords: Zero-lower bound on nominal interest rates, optimal monetary policy, banks, costly enforcement.

JEL Codes: E31, E40, E44, E52, E58, E62, E63.

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†Banco de Portugal, Universidade Catolica Portuguesa, and Centre for Economic Policy Research. Email: mihcarvalho@bportugal.pt

‡European Central Bank, Directorate General Research, Postfach 160319, D-60066 Frankfurt am Main. Email: fiorella.de_fiore@ecb.int.

§Banco de Portugal, Universidade Catolica Portuguesa, and Centre for Economic Policy Research. Email: pteles@ucp.pt

¶European Central Bank, Directorate General Research, Postfach 160319, D-60066 Frankfurt am Main. Email: oreste.tristani@ecb.int.

1 Introduction

As long as cash cannot be directly taxed, nominal interest rates cannot be negative. This restricts what monetary policy can achieve, and this restriction seems to be particularly relevant in times of severe financial disruption, as in the recent recession.

Most of the literature has approached the zero bound issue using models of sticky prices. In those models, interest rates determine intertemporal decisions and ought to be very low, possibly negative. They may nonetheless be high because nominal rates cannot fall below zero or because there is deflation.

During the recent financial crisis, as in many other historical episodes where interest rates have been close to the zero bound, interest rates that are relevant for spending decisions have been high because of increased spreads rather than because of deflation. Figure 1 and 2 plot the evolution of credit spreads[1] and the real interest rate in the euro area and the U.S., respectively. Since 2009, the overnight interest rates were very close to the zero-bound, while inflation remained positive - with the exception of 2009Q3 - and did not significantly deviate from pre-crisis averages. Expected inflation was well-anchored at positive levels, contributing to the low observed path of real interest rates. On the contrary, credit spreads increased sharply during 2008-09, before stabilizing to higher than pre-crisis levels.

This evidence casts doubts on the more conventional approach to the relevance of the zero bound in a financial crisis, involving a rigidity in the adjustment of prices together with a shock to the discount factor. It raises a number of questions: Can the zero bound be a binding constraint in response to shocks that increase credit spreads? How can monetary and fiscal policy be used to optimally affect lending and borrowing rates, and credit spreads? How relevant is the zero bound for optimal policy when financial markets are imperfect?

We consider models with financial frictions of different types. In particular, we consider the model with costly enforcement of Gertler and Kiyotaki (2010), where bankers can divert part of the assets. They must hold internal funds in order for that not to be the case. We also consider the costly state verification model of De Fiore, Teles and Tristani (2011), where creditors have limited information on the quality of the loans of the banks, but where they can access that information by paying a cost associated with bankruptcy. It is part of the optimal

[1] Credit spreads are measured as spreads between AAA and BBB corporate bonds yields.

contract that banks also hold internal funds. The return on those internal funds is going to be higher than the return on bank debt, and credit spreads also reflect that.

We study the effects of financial shocks and other shocks taking into account the restriction that the nominal interest rate cannot be negative. Our main results can be summarized as follows.

The optimal nominal interest rate would be negative, if that was a possibility. That way, even if there would still be spreads, the effects of those on the allocations would be minimized - in different ways depending on how financial frictions are modeled.

The subsidization of consumption achieved through negative nominal interest rate could alternatively be achieved with tax policy. In the presence of lump-sum taxes, there is an equivalence between nominal interest rates and subsidies to debt repayment. A system of appropriately chosen tax/subsidies could be used to overcome the restriction imposed by the zero-lower bound and to achieve the first best allocation.

When only distortionary taxes are available to finance the subsidies, it is no longer possible to overcome the zero bound constraint on monetary policy. The Ramsey planner is not able to achieve the first best. In response to technology shocks, it is however possible to replicate the response of real variables that would arise in the first best. This is not possible in response to financial shocks, which affect leverage and credit spreads.

Our model relates to a large literature that has addressed the relevance of the zero-lower bound on nominal interest rates as a constraint for monetary policy.

Most papers in this literature consider sticky prices as the only frictions (Eggertsson and Woodford, 2003, Adam and Billi, 2006, and Nakov, 2008). In those models, the economy reaches the zero-lower bound in response to negative demand shocks. The optimal monetary policy would reduce interest rates aggressively in order to replicate the real interest rate that would arise under flexible price. The zero-lower bound prevents it from doing so, generating negative pressures on output and inflation, which further increase the real interest rate and lead the economy to fall into liquidity traps.

The key finding of that literature is that the likelihood of being at the zero bound and the severity of the ensuing recession can be reduced by committing to keep interest rates low in the future for a longer period than optimal in the absence of the ZLB. Such promise, if credible, generates high inflation expectations, reduces the current real interest rate and stimulates the economy (Eggertsson and Woodford, 2003). Another key finding is that fiscal stimulus can be very powerful when the economy is at the zero bound, due to the presence of large fiscal multipliers (Christiano, Eichenbaum and Rebelo, 2011).[2]

Different conclusions are reached by Correia, Farhi, Nicolini and Teles (2013). The authors show that, when the zero-lower bound is a constraint for monetary policy, fiscal policy can be used in a budget neutral way and in a time-consistent matter. By setting producer price to zero, a path of increasing consumption taxes that induce the appropriate path of expected inflation, and a corresponding path of declining income taxes, the optimal policy can achieve the first-best allocation and costlessly overcome the restriction imposed by the zero-lower bound. Our paper differs in the type of frictions and shocks which make the zero bound a restriction for monetary policy, and in the ability of fiscal policy to overcome that restriction at no additional cost.

Our model is not the first to address the issue of the zero bound in models where the key distortion is due to imperfect financial markets (see e.g. De Fiore and Tristani, 2012, Gertler and Karadi, 2010, and Eggertsson and Krugman, 2010). Among these papers, however, only De Fiore and Tristani (2012) characterize the optimal policy response to shocks that increase credit spreads and drive interest rates to the zero bound. That paper, however, does not consider the possibility to overcome the zero bound through tax policy.

The paper proceeds as follows. In section 2, we describe the environment. In section 3, we characterize the steady state. We derive the optimal monetary policy in steady state, in the case when either interest rates can be negative or the government can provide credit subsidies to firms. Then, we consider the case when only distortionary taxes are available. In section 4, we establish an equivalence between nominal interest rates and credit subsidies in our dynamic economy, irrespective of whether taxes are lump-sum or distortionary. We also show that, if taxes are lump-sum, it is possible to achieve the first best by using credit subsidies, when the zero bound is a constraint for monetary policy. In section 5, we analyze a model where the financial friction arises because of costly state verification rather than because of costly enforcement of contracts. We show that in this environment the optimal policy cannot achieve the first-best. In section 6, we present numerical results. In section 7, we conclude.

[2] See also Werning (2012).

2 The model

2.1 The household

The household is composed of workers and bankers: with probability $1-\theta$ bankers exit and become workers, and with probability θ they remain bankers. The fraction of bankers is f and workers $1-f$. Bankers and workers share consumption.

The household preferences are

$$\text{Max } E_t \sum_{t=0}^{\infty} \beta^t \left[\log C_t - \frac{\chi}{1+\phi} N_t^{1+\varphi} \right]$$

In the beginning of period t, the household has nominal wealth $\mathbb{W}_t$, and purchases $E_t Q_{t,t+1} B_{t,t+1}$ in state contingent nominal claims where $Q_{t,t+1}$ is the price in period t of a unit of money in period $t+1$, in some state, normalized by the probability of occurrence of the state, as well as deposits D_t. In the beginning of the following period the nominal wealth $\mathbb{W}_{t+1}$ includes the state contingent units of money $B_{t,t+1}$, the gross return on deposits $R_t D_t$, the dividends received from the banks Π_t^b, the wage income $W_t N_t$, minus the consumption expenditures $P_t C_t$, and minus the lump sum taxes T_t. The flow of funds constraints of the households are

$$E_t Q_{t,t+1} B_{t,t+1} + D_t \leq \mathbb{W}_t, \tag{1}$$

$$\mathbb{W}_{t+1} = B_{t,t+1} + R_t D_t + \Pi_t^b + W_t N_t - P_t C_t - T_t$$

The first order conditions of the households problem include

$$-\frac{u_C(t)}{u_N(t)} = \frac{P_t}{W_t}, \tag{2}$$

$$\frac{u_C(t)}{\beta u_C(t+1)} = Q_{t,t+1}^{-1} \frac{P_t}{P_{t+1}}, \tag{3}$$

$$\frac{u_C(t)}{P_t} = R_t E_t \frac{\beta u_C(t+1)}{P_{t+1}}, \tag{4}$$

2.2 Firms

In the economy there is a representative firm endowed with a stochastic technology that transforms N_t units of labor into $Y_t = A_t N_t$ units of output. In the beginning of the period, the firm needs to borrow nominal funds S_t in order to pay the wage bill,

$$W_t N_t \leq S_t.$$

Firms must demand money in the assets market at the beginning of the period in order to pay labor at the end of production in the goods market.[3]

Profits each period can be written as

$$\Pi_t^f = P_t Y_t - W_t N_t - \left[R_t^l \left(1 - \tau_t^l\right) - 1\right] S_t,$$

where P_t is the price level, R_t^l is the gross interest rate on the loans to the firms, and τ_t^l is a government subsidy on debt repayment.

Assuming that the cash in advance constraint holds with equality, we can write the optimality conditions as

$$P_t A_t = W_t R_t^l \left(1 - \tau_t^l\right).$$

2.3 Banks

Each bank j channels funds from depositors to the firms. Because of a costly enforcement problem, each bank must have internal funds, $Z_{j,t}$. The bank borrows $D_{j,t}$ and lends $S_{j,t}$. It follows that

$$S_{j,t} = D_{j,t} + Z_{j,t}$$

The net worth of the bank evolves according to

$$Z_{j,t+1} = R_t^l S_{j,t} - R_t D_{j,t}.$$

Combining the two conditions above, we can write

$$Z_{j,t+1} = \left(R_t^l - R_t\right) S_{j,t} + R_t Z_{j,t}$$

Note that bank profits are given by

$$\overline{\Pi}_{j,t+1}^b = \left(R_t^l - 1\right) S_{j,t} - \left(R_t - 1\right) D_{j,t}$$

[3] The way money enters the economy is through open market operations, where the government exchanges money for government bonds. We assume that only banks have access to open market operations and that banks do not need to hold money, so they immediately pass it on to firms as loans. Note that households pay for goods in the financial market at the beginning of the next period, using both money and other assets. This constraint can equivalently be written as $W_t N_t \leq M_t$, where M_t is outside money, together with a trivial flow of funds constraint requiring that $M_t = S_t$, i.e. that money M_t is the counterpart of the loan S_t.

so that

$$Z_{j,t+1} = \overline{\Pi}^b_{j,t+1} + Z_{j,t}$$

Bankers maximize expected terminal wealth, $V_{j,t}$, where

$$V_{j,t} = E_t \sum_{s=0}^{\infty} (1-\theta)\, \theta^s Q_{t,t+1+s} Z_{j,t+1+s} = E_t \sum_{s=0}^{\infty} (1-\theta)\, \theta^s Q_{t,t+1+s} \left[\left(R^l_{t+s} - R_{t+s} \right) S_{j,t+s} + R_{t+s} Z_{j,t+s} \right]$$

As in Gertler and Kiyotaki (2010), bankers can appropriate a fraction λ of assets $S_{j,t}$. The incentive compatibility constraint is

$$V_{j,t} \geq \lambda S_{j,t}.$$

As shown in appendix A, the value $V_{j,t}$ can be written as:

$$V_{j,t} = \upsilon_t S_{j,t} + \eta_t Z_{j,t}$$

where

$$\upsilon_t = E_t \left\{ (1-\theta)\, Q_{t,t+1} \left(R^l_t - R_t \right) + Q_{t,t+1} \theta \frac{S_{j,t+1}}{S_{j,t}} \upsilon_{t+1} \right\}$$

and

$$\eta_t = E_t \left\{ (1-\theta) + Q_{t,t+1} \theta \frac{Z_{j,t+1}}{Z_{j,t}} \eta_{t+1} \right\}.$$

The incentive constraint can then be written as

$$\upsilon_t S_{j,t} + \eta_t Z_{j,t} \geq \lambda S_{j,t} \tag{5}$$

For $Z_{j,t} > 0$, the constraint will bind only if $\upsilon_t < \lambda$, which we assume to be the case. Then

$$S_{j,t} = \frac{\eta_t}{(\lambda - \upsilon_t)} Z_{j,t} \equiv \phi_t Z_{j,t}.$$

This is the private assets to equity ratio, which we refer to as leverage ratio. More specifically the debt to equity ratio is

$$\frac{S_{j,t} - Z_{j,t}}{S_{j,t}} = \frac{\phi_t - 1}{\phi_t} = 1 - \frac{1}{\phi_t} < 1.$$

The evolution of net worth can now be simplified to

$$Z_{j,t+1} = \left[\left(R^l_t - R_t \right) \phi_t + R_t \right] Z_{j,t}$$

The growth rates of Z_j and S_j are given by

$$\zeta_{t,t+1} = \frac{Z_{jt+1}}{Z_{jt}} = \left(R^l_t - R_t \right) \phi_t + R_t$$

$$\varkappa_{t,t+1} = \frac{S_{jt+1}}{S_{jt}} = \frac{\phi_{t+1}}{\phi_t}\left[\left(R_t^l - R_t\right)\phi_t + R_t\right]$$

We can now write the expressions for υ_t and η_t as

$$\upsilon_t = (1-\theta)\frac{R_t^l - R_t}{R_t} + E_t\left[Q_{t,t+1}\theta\varkappa_{t,t+1}\upsilon_{t+1}\right]$$

and

$$\eta_t = E_t\left\{(1-\theta) + Q_{t,t+1}\theta\zeta_{t,t+1}\eta_{t+1}\right\}$$

The internal funds of bankers is the sum of the funds of surviving bankers Z_{et+1} and entering bankers Z_{nt+1}. Since a fraction θ of bankers survive,

$$Z_{et} = \theta\left[\left(R_{t-1}^l - R_{t-1}\right)\phi_{t-1} + R_{t-1}\right]Z_{t-1}.$$

The remaining fraction, $1-\theta$, die and transfer back its internal funds to the households at the end of the period. The households then transfer to the entering banks the fraction $\frac{\omega}{1-\theta}$ of these assets at t,

$$Z_{nt} = \omega\left[\left(R_{t-1}^l - R_{t-1}\right)\phi_{t-1} + R_{t-1}\right]Z_{t-1}.$$

We can then write

$$Z_t = Z_{et} + Z_{nt} = (\theta+\omega)\left[\left(R_{t-1}^l - R_{t-1}\right)\phi_{t-1} + R_{t-1}\right]Z_{t-1}$$

Note that the internal funds are not a separate asset. They are simply a balance sheet item defined as the difference between banks' assets–loans and liabilities–deposits.

Recall that $\overline{\Pi}_{j,t}^b = Z_{j,t} - Z_{j,t-1}$. Each bank accumulates profits $\overline{\Pi}_{j,t}^b$ as net worth until the banker dies, at which point the remaining net worth is transferred to the households as dividends.

The net dividends retained by the household after transferring net worth to new banks are therefore

$$\Pi_t^b = \left(\frac{1}{\theta+\omega} - 1\right)Z_t.$$

2.4 Government

The government spends G_t, issues money M_t and state contingent government bonds $B_{t,t+1}^g$, gives credit subsidies $\tau_t^l R_t^l S_t$ and raises lump sum taxes T_t. The budget constraint is given by

$$E_t Q_{t,t+1} B_{t,t+1}^g + M_t \leq -\mathbb{W}_t^g, \tag{6}$$

where $-\mathbb{W}^g_{t+1}$ are government liabilities

$$-\mathbb{W}^g_{t+1} = B^g_{t,t+1} + \tau^l_t R^l_t S_t + M_t + P_t G_t - T_t \tag{7}$$

Notice that the net wealth of all agents in the economy must be zero. Total net wealth is the sum of households' wealth, government wealth and banks' net worth, i.e.

$$\mathbb{W}_{t+1} + \mathbb{W}^g_{t+1} + Z_t = 0$$

2.5 Market clearing

The resource constraint is

$$C_t + G_t = A_t N_t$$

2.6 Equilibrium conditions

The equilibrium conditions can be summarized by

$$-\frac{u_C(t)}{u_N(t)} = \frac{R^l_t\left(1-\tau^l_t\right)}{A_t}, \tag{8}$$

$$C_t + G_t = A_t N_t \tag{9}$$

$$\frac{A_t}{R^l_t\left(1-\tau^l_t\right)} N_t = \phi_t \frac{Z_t}{P_t} \tag{10}$$

$$\phi_t = \frac{\eta_t}{\lambda - \upsilon_t} \tag{11}$$

$$Z_t = (\theta + \omega)\left[\left(R^l_{t-1} - R_{t-1}\right)\phi_{t-1} + R_{t-1}\right] Z_{t-1} \tag{12}$$

$$\frac{u_C(t)}{P_t} = R_t E_t \frac{\beta u_C(t+1)}{P_{t+1}}, \tag{13}$$

and

$$\zeta_{t,t+1} = \left(R^l_t - R_t\right)\phi_t + R_t \tag{14}$$

$$\varkappa_{t,t+1} = \frac{\phi_{t+1}}{\phi_t}\left[\left(R^l_t - R_t\right)\phi_t + R_t\right] \tag{15}$$

$$\upsilon_t = E_t\left\{(1-\theta) Q_{t,t+1}\left(R^l_t - R_t\right) + Q_{t,t+1}\theta\varkappa_{t,t+1}\upsilon_{t+1}\right\} \tag{16}$$

$$\eta_t = E_t\left\{(1-\theta) + Q_{t,t+1}\theta\zeta_{t,t+1}\eta_{t+1}\right\} \tag{17}$$

In this economy, if it was not for the predetermination of internal funds, money would be neutral, in the sense that an increase in Z_0 would increase all price levels and nominal quantities by the same percentage, keeping interest rates and allocations unchanged. Because

Z is predetermined, however, increasing all nominal quantities and price levels would not be possible without changing the real allocation. Equation (12) shows that, for a given Z_{t-1}, an increase in Z_t would not be consistent with the observed levels of the policy rate R_{t-1}, the credit spread, $R^l_{t-1} - R_{t-1}$, and leverage, ϕ_{t-1}. The price level is not irrelevant in this economy.

It is useful to compare the equilibrium allocation with the one that would arise in the absence of distortions. The first-best allocation can be obtained as the solution to the maximization of households' preferences subject to the resource constraint. The efficiency conditions are given by

$$-\frac{u_C(t)}{u_N(t)} = \frac{1}{A_t}, \tag{18}$$

$$C_t + G_t = A_t N_t. \tag{19}$$

Comparison of condition (18) with (8) shows that the distortion introduced by costly enforcement and by the death probability of bankers, which limit their ability to accumulate internal funds, shows up as a positive lending rate R^l_t. Only when $R^l_t = 1$, it is possible to achieve the first best allocation in our economy.

3 Optimal steady state policy

We first characterize the steady state of our economy. Then, we derive the optimal monetary policy in the case when either interest rates can be negative or the government can provide credit subsidies to firms. Finally, we consider the case when only distortionary taxes are available.

3.1 The steady state

In a steady state with constant gross inflation Π, we have $\frac{P_{t+1}}{P_t} = \frac{W_{t+1}}{W_t} = \frac{S_{t+1}}{S_t} = \frac{Z_{t+1}}{Z_t} = \Pi$. The steady state conditions are given by

$$\frac{1}{\chi C N^{\varphi}} = \frac{R^l\left(1-\tau^l\right)}{A}$$

$$C + G = AN$$

$$R\frac{\beta}{\Pi} = 1$$

$$\frac{A}{R^l\left(1-\tau^l\right)}N = \phi\frac{Z_t}{P_t}$$

$$\Pi = (\theta + \omega)\left[\left(R^l - R\right)\phi + R\right] \tag{20}$$

where

$$\phi = \frac{\eta}{\lambda - \upsilon}$$

$$\upsilon = (1-\theta)\frac{\beta}{\Pi}\left(R^l - R\right) + \frac{\beta}{\Pi}\theta\varkappa\upsilon \tag{21}$$

$$\eta = (1-\theta) + \frac{\beta}{\Pi}\theta\zeta\eta \tag{22}$$

$$\varkappa = \zeta = \left(R^l - R\right)\phi + R \tag{23}$$

Manipulating the conditions (21) with (23) above, we get

$$\eta = \frac{1-\theta}{1-\theta\left[\left(\frac{R^l}{R}-1\right)\phi + 1\right]} \tag{24}$$

and

$$\upsilon = \frac{(1-\theta)\left(\frac{R^l}{R}-1\right)}{1-\theta\left[\left(\frac{R^l}{R}-1\right)\phi + 1\right]}. \tag{25}$$

It follows that

$$\phi = \frac{\eta}{\lambda - \upsilon} = \frac{1-\theta}{\lambda\left[1-\theta\left[1+\left(\frac{R^l}{R}-1\right)\phi\right]\right] - (1-\theta)\left(\frac{R^l}{R}-1\right)}$$

implying that

$$1-\theta-(1-\theta)\left[\lambda - \left(\frac{R^l}{R}-1\right)\right]\phi + \theta\lambda\left(\frac{R^l}{R}-1\right)\phi^2 = 0. \tag{26}$$

Notice that equation (**??**) can be written as

$$\frac{\beta-\omega-\theta}{\theta+\omega} = \left(\frac{R^l}{R}-1\right)\phi,$$

where it must be that $\frac{\beta}{\theta+\omega} > 1$, or $\beta > \theta + \omega$. This expression together with equation (26) can be used to obtain an expression for leverage

$$\phi = \frac{\beta(1-\theta)}{\lambda\left[\theta(1-\beta)+\omega\right]}. \tag{27}$$

The spread is given by

$$\frac{R^l}{R} - 1 = \frac{\lambda(\beta-\theta-\omega)\left[\theta(1-\beta)+\omega\right]}{(\theta+\omega)\beta(1-\theta)} \tag{28}$$

and is thus independent of inflation.

3.2 Optimal monetary and fiscal policy

With lump sum taxes, if the nominal interest could be negative, the Ramsey planner could implement the first best with monetary policy only, i.e. by setting $\tau^l = 0$.

The optimal policy is to set $R^l = 1$, for all t. This achieves the first-best allocation as the marginal rate of substitution equates the marginal rate of transformation,

$$\frac{1}{\chi C N^{\varphi}} = \frac{1}{A}.$$

and the resource constraint is satisfied

$$C + G = AN.$$

There is always a $R < 1$ that can satisfy the remaining equilibrium conditions, for a given P:

$$R\frac{\beta}{\Pi} = 1$$

$$AN = \phi\frac{Z}{P}$$

$$\Pi = (\theta + \omega)\left[(1 - R)\,\phi + R\right]$$

where

$$\phi = \frac{\beta\,(1-\theta)}{\lambda\left[\theta\,(1-\beta) + \omega\right]}.$$

The solution requires $R < 1$ because otherwise the bank would not be willing to lend.

The same allocation could be achieved when the zero-lower bound on nominal interest rates is imposed, $R \geq 1$, for an appropriate choice of credit subsidy τ^l. In this case, the first-best allocation can be achieved through a combination of $R^l > 1$, $R = 1$ and τ^l such that $R^l\left(1 - \tau^l\right) = 1$.

These results show that the optimal policy in the presence of lump-sum taxes can achieve the first-best and circumvent the problem of the zero bound. The optimal subsidy can be obtained using equation (28) and is given by

$$\frac{\tau^l}{1-\tau^l} = \frac{\lambda\,(\beta - \theta - \omega)\left[\theta\,(1-\beta) + \omega\right]}{(\theta + \omega)\,\beta\,(1-\theta)} > 0.$$

The first-best allocation cannot be achieved when only distortionary taxes are available. From the budget constraint of the government, (6) and (7), it is clear that when $T_t = 0$, a credit subsidy can only be financed with either money creation of by raising public debt.

This requires a positive R, which is not be consistent with the achievement of the first-best allocation.

The zero bound is a constraint which cannot be costlessly overcome when the government needs to raise revenues in a distortionary fashion.

4 Equivalence between credit subsidies and interest rates

We establish the equivalence between nominal interest rates and credit subsidies in our model economy. This equivalence holds irrespective of whether taxes are lump-sum or distortionary.

The equilibrium conditions for the economy are given by equations (8)-(17) and can be written as

$$-\frac{u_C(t)}{u_N(t)} = \frac{R_t^l\left(1-\tau_t^l\right)}{A_t}, \tag{29}$$

$$C_t + G_t = A_t N_t$$

$$\frac{A_t}{R_t^l\left(1-\tau_t^l\right)} N_t = \phi_t \frac{Z_t}{P_t}$$

$$\phi_t = \frac{\eta_t}{\lambda - \upsilon_t}$$

$$Z_t = (\theta+\omega) R_{t-1}\left[\left(\frac{R_{t-1}^l}{R_{t-1}} - 1\right)\phi_{t-1} + 1\right] Z_{t-1}$$

$$\frac{u_C(t)}{P_t} = R_t E_t \frac{\beta u_C(t+1)}{P_{t+1}},$$

and

$$\zeta_{t,t+1} = R_t\left[\left(\frac{R_t^l}{R_t} - 1\right)\phi_t + 1\right]$$

$$\varkappa_{t,t+1} = \frac{\phi_{t+1}}{\phi_t} R_t\left[\left(\frac{R_t^l}{R_t} - 1\right)\phi_t + 1\right]$$

$$\upsilon_t = E_t\left\{(1-\theta) Q_{t,t+1} R_t\left(\frac{R_t^l}{R_t} - 1\right) + Q_{t,t+1}\theta \frac{\phi_{t+1}}{\phi_t} R_t\left[\left(\frac{R_t^l}{R_t} - 1\right)\phi_t + 1\right]\upsilon_{t+1}\right\}$$

$$\eta_t = E_t\left\{(1-\theta) + Q_{t,t+1}\theta R_t\left[\left(\frac{R_t^l}{R_t} - 1\right)\phi_t + 1\right]\eta_{t+1}\right\}$$

$$Q_{t,t+1} = \frac{u_C(t) P_{t+1}}{\beta u_C(t+1) P_t}.$$

To show the equivalence, take an allocation, $\{C_t, N_t\}$ and $\left\{\phi_t, \frac{R_t^l}{R_t}, \eta_t, \upsilon_t\right\}$, where $R_t^l > R \geq 1$. Take a path for $\left\{\tau_t^l = 0\right\}$, and an alternative path $\left\{\widetilde{\tau}_t^l\right\}$ such that

$$R_t^l\left(1-\tau_t^l\right) = \widetilde{R}_t^l\left(1-\widetilde{\tau}_t^l\right), \tag{30}$$

$$\frac{R_t^l}{R_t} = \frac{\widetilde{R}_t^l}{\widetilde{R}_t}, \tag{31}$$

$$\widetilde{Q}_{t,t+1}\widetilde{R}_t = Q_{t,t+1}R_t, \tag{32}$$

and

$$\widetilde{R}_t \geq 1,$$

for all t. Notice that t is always possible to find a $\left\{\widetilde{\tau}_t^l\right\}$, such that restriction (30)-(32) are satisfied and $\widetilde{R}_t \geq 1$.

Since Z_0 cannot move, P_0 should not move either, so $P_0 = \widetilde{P}_0$. Under the alternative path, the spreads, leverage, weights are all invariant. Only the nominal variables grow at a different rate, keeping the real variables constant.

This shows the equivalence result between two alternative instruments, the nominal interest rate and the credit subsidy, $\left\{R_t, \tau_t^l\right\}$.

Is it possible to achieve the first best by using credit subsidies rather than setting negative interest rates and $R_t^l = 1$?

The first best allocation requires

$$R_t^l\left(1 - \tau_t^l\right) = 1$$

Let's also set $R_t = 1$. It is possible to satisfy the other equilibrium conditions and achieve the first-best allocation:

$$A_0N_0 = \phi_0\frac{Z_0}{P_0}$$

is satisfied with P_0,

$$\frac{u_C(t)}{P_t} = E_t\frac{\beta u_C(t+1)}{P_{t+1}}, \tag{33}$$

is satisfied with P_{t+1}, $t \geq 0$,

$$A_tN_t = \phi_t\frac{Z_t}{P_t},\ t \geq 1,$$

is satisfied by Z_t,

$$Z_t = (\theta + \omega)R_{t-1}\left[\left(\frac{R_{t-1}^l}{R_{t-1}} - 1\right)\phi_{t-1} + 1\right]Z_{t-1},\ t \geq 1$$

is satisfied by R_{t-1}^l, $t \geq 1$,

$$\phi_t = \frac{\eta_t}{\lambda - \upsilon_t}$$

is satisfied by ϕ_t, and the following conditions restrict the variables υ_t, η_t, $\zeta_{t,t+1}$, $\varkappa_{t,t+1}$, $Q_{t,t+1}$

$$\zeta_{t,t+1} = R_t \left[\left(\frac{R_t^l}{R_t} - 1 \right) \phi_t + 1 \right]$$

$$\varkappa_{t,t+1} = \frac{\phi_{t+1}}{\phi_t} R_t \left[\left(\frac{R_t^l}{R_t} - 1 \right) \phi_t + 1 \right]$$

$$\upsilon_t = E_t \left\{ (1-\theta) Q_{t,t+1} R_t \left(\frac{R_t^l}{R_t} - 1 \right) + Q_{t,t+1} \theta \frac{\phi_{t+1}}{\phi_t} R_t \left[\left(\frac{R_t^l}{R_t} - 1 \right) \phi_t + 1 \right] \upsilon_{t+1} \right\}$$

$$\eta_t = E_t \left\{ (1-\theta) + Q_{t,t+1} \theta R_t \left[\left(\frac{R_t^l}{R_t} - 1 \right) \phi_t + 1 \right] \eta_{t+1} \right\}$$

$$Q_{t,t+1} = \frac{u_C(t) P_{t+1}}{\beta u_C(t+1) P_t}.$$

Our results show that the optimal policy can achieve the first-best by setting $R_t = 1$ and $R_t^l \left(1 - \tau_t^l\right) = 1$. The same allocation can also be achieved with a path for the policy rate that is higher than zero, $R_t > 1$, and with a higher subsidy τ_t^l that compensates not only the spread but also the policy rate.

5 Costly enforcement vs costly state verification

We analyze the robustness of our conclusions to the specific type of financial market distortion considered. We do so by analyzing the model of De Fiore, Teles and Tristani (2011). In this latter, as here, firms borrows in advance of production to pay nominal wages. However, the financial imperfection takes the form of costly state verification. Firms are subject to idiosyncratic shocks which may force them to default on their debt. Banks cannot observe the realization of the shocks, although they can costly monitor firms' production. In this model, firms' assets and liabilities are denominated in nominal terms and predetermined when shocks occur. Monetary policy can therefore affect the real value of funds used to finance production.

The main difference relative to the model presented in section 2 is that monitoring costs imply a resource loss for the economy. Therefore, the optimal policy cannot achieve the first best.

[TO BE COMPLETED...]

6 Numerical analysis

This section illustrates the quantitative features of the model described in section 2 through an impulse response analysis.

We only have five parameters to calibrate. We use standard values for utility parameters: $\beta = 0.99$ and $\varphi = 0$. Concerning the financial sector parameters, we follow the approach in Gertler and Karadi (2011). Specifically we use the same value as in that paper for the fraction of funds that can be diverted from the bank: $\lambda = 0.381$. We then calibrate bankers' survival probability θ and the proportional transfer to entering bankers ω so as to obtain a certain target value for the annualized steady state spread and for the steady state leverage ratio. We choose values of approximately 2% for spreads and 2 for leverage. This implies $\theta = 0.9234$ and $\omega = 0.01$.

Government expenditure is set to zero in the figures.

6.1 Optimal response to shocks at the ZLB

Figure 3 shows the impulse responses to a 1% innovation in technology–the shock is assumed to be serially uncorrelated–when optimal policy is constrained by the zero bound on nominal interest rates. All variables are in deviation from the steady state.

The notable feature emerging from figure 3 is that consumption responds to the shock exactly as it would in the first best. It increases one-to-one with the shock, while hours (not reported in the figure) remain constant. To deliver this outcome, optimal policy must ensure that leverage, hence spreads, do not change in reaction to the shock. In turn, this requires that the increase in the real value of loans necessary to finance the increase in production, $s_t = S_t/P_t$, is accompanied by a one-to-one increase in real value of net worth $z_t = Z_t/P_t$. This can be achieved through an impact fall in the price level, which must be reversed after one period to ensure that s_t and z_t return to their steady state values once the shock is reabsorbed. In the third period after the shock, all variables are back to steady state.

Figure 4 shows that responses are very different in reaction to a financial shock, which is here represented by a 1% increase in λ–this shock is also assumed to be serially uncorrelated. As in Figure 3, optimal policy is constrained by the zero bound on nominal interest rates.

The temporary increase in λ, the fraction of bank's funds that can be diverted by the banker, has two effects in the model. On the one hand, for given amount of loans, depositors will demand an increase in banks' internal funds, i.e. a reduction in banks' leverage ϕ. The fall in leverage could be brought about by either a fall in loans, or an increase in net worth, or both. To minimize the repercussions of the shock on consumption, policy reacts with an impact reduction in the price level, which has the advantage of cushioning the fall in real value of loans, but also leads to an increase in the real value of net worth. On the other hand, banks' profits must increase to ensure that bankers do not divert assets in equilibrium. The loan rate–i.e. spreads, given that the deposit rate is fixed at zero–must increase. The increase in banks' profits implies that banks' net worth is too high in the following period, when λ returns to the steady state. As a result, leverage is too low, so the loan rate must fall below its steady state level, to reduce banks' profits and ensure a slow depletion of net worth until leverage is back at the steady state.

6.2 Optimal response to shocks when R is unconstrained

Figure 5 shows again impulse responses to a 1% innovation in technology, but focuses on the case of a permanent shock. In this case, fiscal policy is used to circumvent the ZLB constraint. The figure shows the notional levels of the nominal deposit rate which is implemented through the state contingent subsidy described above. To emphasize that the notional deposit rate is negative in equilibrium, all variables are reported in log levels. The deposit rate and the inflation rate are in annualized percentage terms.

We have already demonstrated above that, if fiscal policy is available and can be financed through lump sum taxes, optimal policy can fully replicate first best allocations. The notional interest rate on loans can be set to zero, to ensure that spreads have no impact on real variables. In reaction to a permanent increase in technology, consumption jumps on impact to its new, higher steady state level, as in the first best. The real interest rate remains unchanged.

A notable feature of the equilibrium shown in figure 5 is that the impact responses of all nominal variables are indeterminate under optimal policy. Different responses of the price level will be accompanied by different interest rates on deposits and different real values of net worth and leverage–three arbitrary examples are shown in the figure. The nominal value of loans will also change one-to-one with the price level, so as to ensure a constant real s. The Ramsey planner is therefore indifferent to the levels of these variables. Nominal indeterminacy has no impact on welfare and spreads are irrelevant for optimal policy.

To understand this result, note that the only channel through which spreads and leverage have an impact on the real economy is through their implications on the level of the interest rate on loans. If the loan rate can be set to zero at all times, as it is in the case considered in Figure 5, it follows that any changes in the interest rate on deposits and in the spread is irrelevant from the macroeconomic perspective.

Note, however, that nominal indeterminacy only characterizes impact impulse responses. After one period, the prices must move to the level necessary to ensure that the real interest rate is consistent with the Euler equation. Impulse responses to all variables except inflation, therefore, are unique as of the second period after the shock.

7 Conclusions

[TO BE COMPLETED...]

Appendix

A Derivation of the coefficients in the leverage function

$$
\begin{aligned}
V_{j,t}\left(S_{j,t}, Z_{j,t}\right) &= (1-\theta) E_t Q_{t,t+1} Z_{j,t+1} + E_t \sum_{s=1}^{\infty} (1-\theta)\,\theta^s Q_{t,t+1+s} Z_{j,t+1+s} = \\
&= (1-\theta) E_t Q_{t,t+1} Z_{j,t+1} + E_t Q_{t,t+1} \theta \sum_{s=0}^{\infty} (1-\theta)\,\theta^s Q_{t+1,t+2+s} Z_{j,t+2+s} = \\
&= (1-\theta) E_t Q_{t,t+1} Z_{j,t+1} + \mathrm{Max} E_t Q_{t,t+1} \theta V_{j,t+1}\left(S_{j,t+1}, Z_{j,t+1}\right)
\end{aligned}
$$

The conjecture for $V_{j,t}\left(S_{j,t}, Z_{j,t}\right)$ is $V_{j,t}\left(S_{j,t}, Z_{j,t}\right) = \upsilon_t S_{j,t} + \eta_t Z_{j,t}$. Assuming the incentive compatibility constraint is binding gives

$$
\upsilon_t S_{j,t} + \eta_t Z_{j,t} = \lambda S_{j,t}
$$

$$
V_{j,t}\left(S_{j,t}, Z_{j,t}\right) = \mathrm{Max}\ \ (1-\theta) E_t Q_{t,t+1} Z_{j,t+1} + \mathrm{Max} E_t Q_{t,t+1} \theta V_{j,t+1}\left(S_{j,t+1}, Z_{j,t+1}\right)
$$

$$
\begin{aligned}
Z_{j,t+1} &= \left(R_t^l - R_t\right) S_{j,t} + R_t Z_{j,t} \\
S_{j,t} &= \frac{\eta_t}{(\lambda - \upsilon_t)} Z_{j,t} \equiv \phi_t Z_{j,t}
\end{aligned}
$$

or

$$
\upsilon_t S_{j,t} + \eta_t Z_{j,t} = \ \ (1-\theta) E_t Q_{t,t+1} \left[\left(R_t^l - R_t\right) S_{j,t} + R_t Z_{j,t}\right] + E_t Q_{t,t+1} \theta \left[\upsilon_{t+1} \varkappa_{t,t+1} S_{j,t} + \eta_{t+1} \zeta_{t,t+1} Z_{j,t}\right]
$$

It follows that

$$
\upsilon_t = E_t \left\{(1-\theta) Q_{t,t+1} \left(R_t^l - R_t\right) + Q_{t,t+1} \theta \varkappa_{t,t+1} \upsilon_{t+1}\right\}
$$

and

$$\eta_t = E_t \left\{ (1-\theta) + Q_{t,t+1}\theta\zeta_{t,t+1}\eta_{t+1} \right\}$$

together with

$$\zeta_{t,t+1} = \left(R_t^l - R_t\right)\phi_t + R_t$$

$$\varkappa_{t,t+1} = \frac{\phi_{t+1}}{\phi_t}\left[\left(R_t^l - R_t\right)\phi_t + R_t\right]$$

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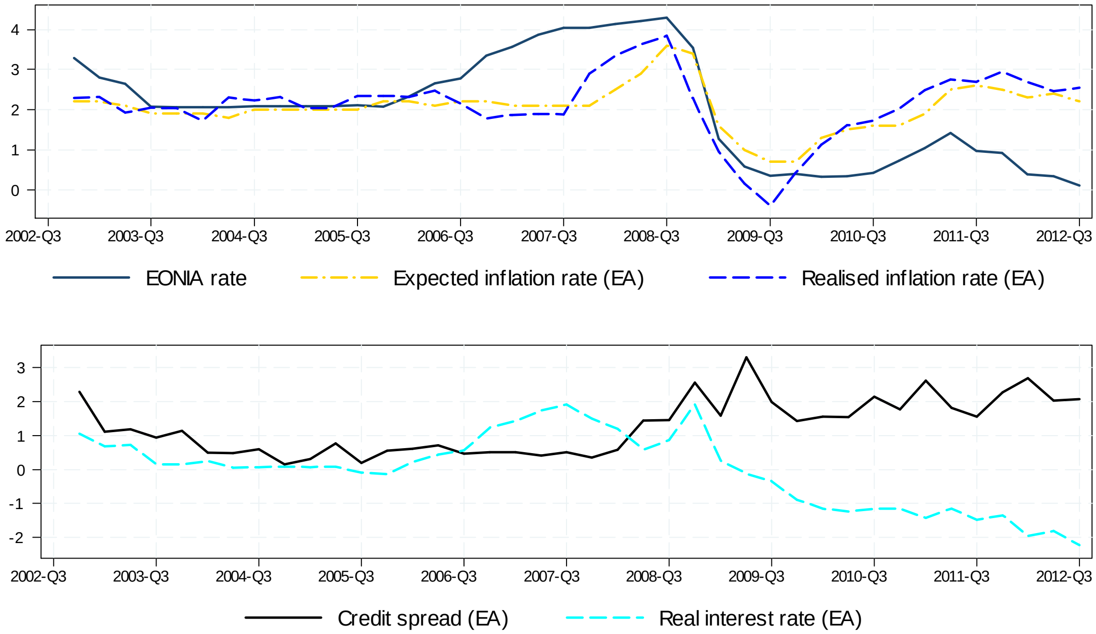
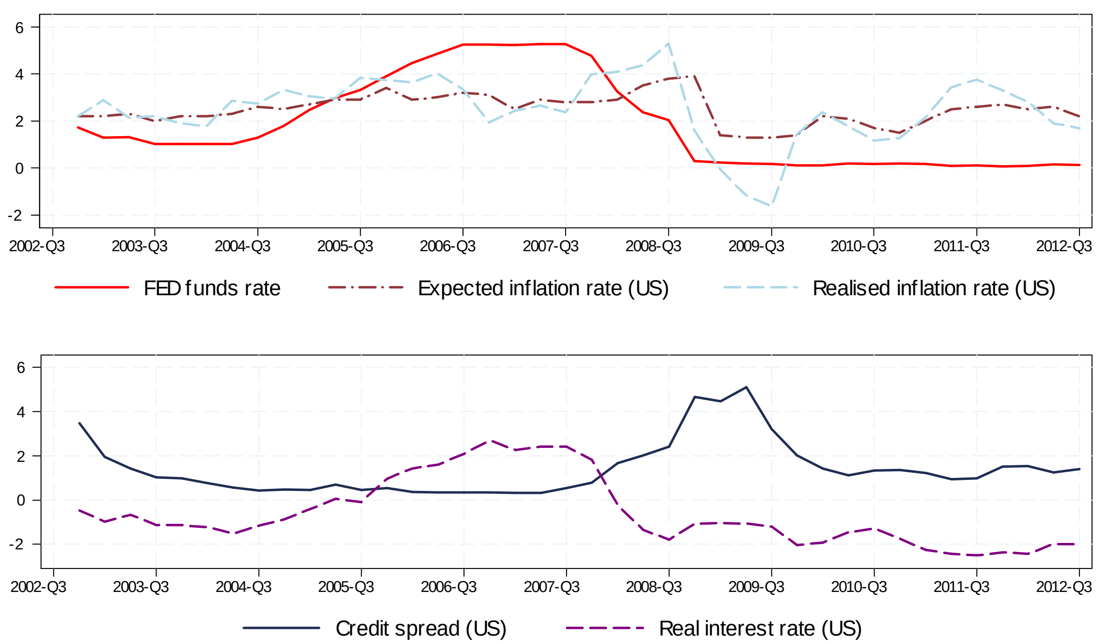


Legend: percentage points, annually.
Source: Datastream, SDW, Eurostat, World Economic Survey.

Figure 1: Real interest rates and credit spreads in the euro area.



Legend: percentage points, annually.
Source: Datastream, SDW, Eurostat, World Economic Survey.

Figure 2: Real interest rates and credit spreads in the U.S.

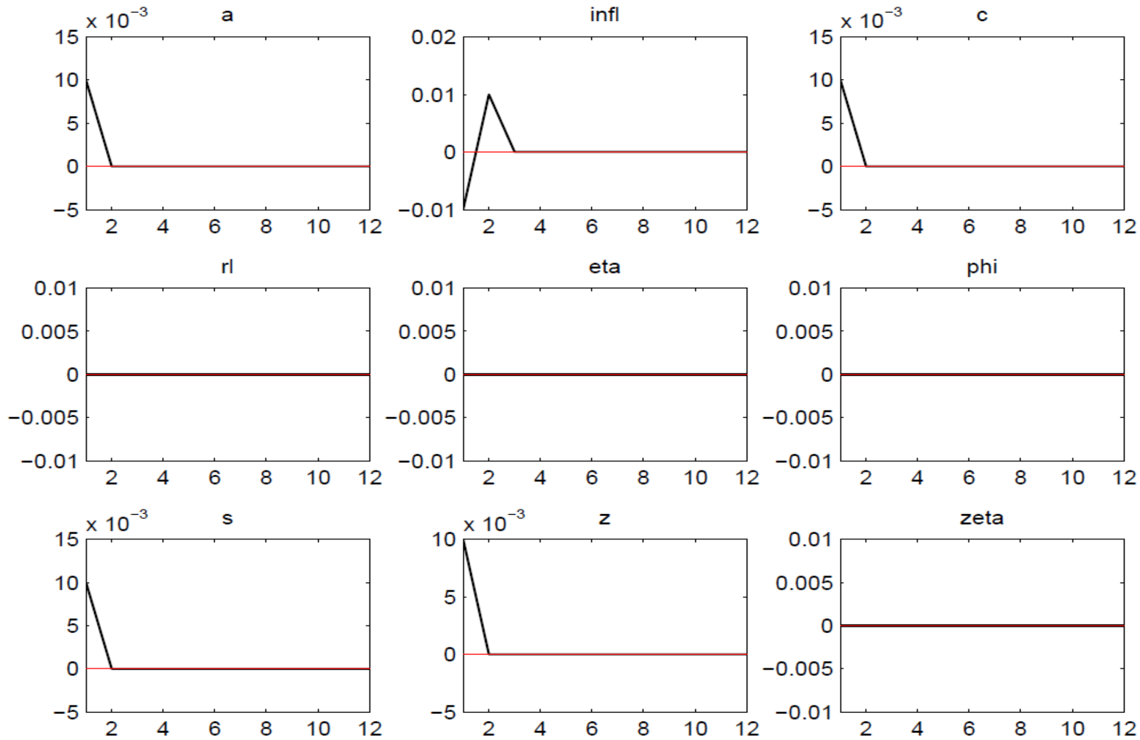


Figure 3: Impulse response to a temporary technology shock under the Ramsey policy.

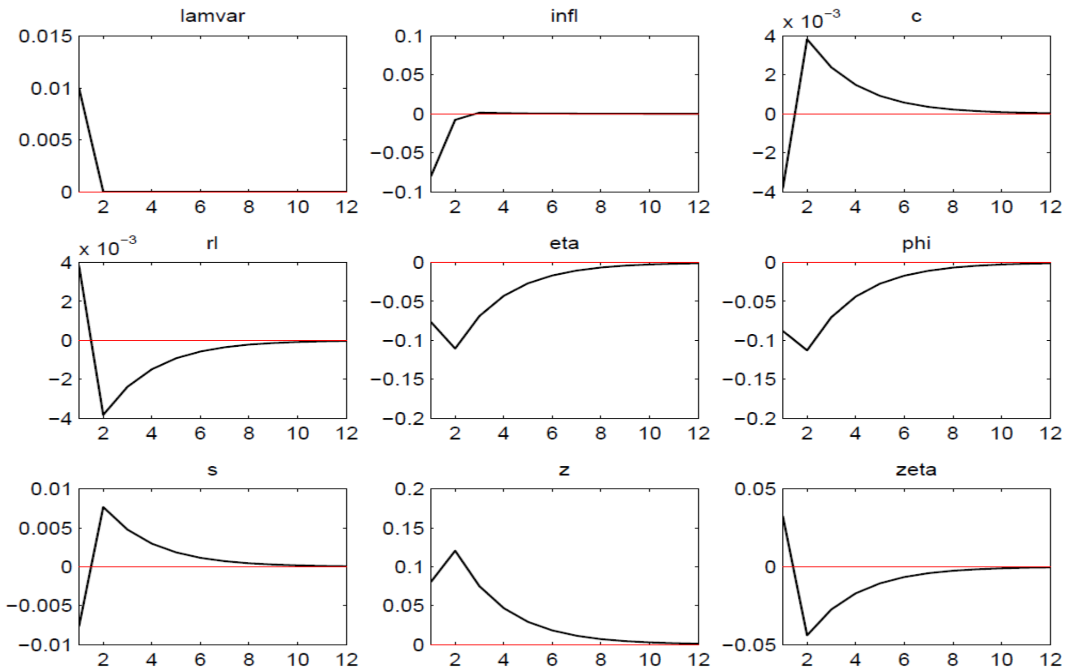


Figure 4: Impulse response to a temporary shock to the share of assets banks can appropriate (λ) under the Ramsey policy.

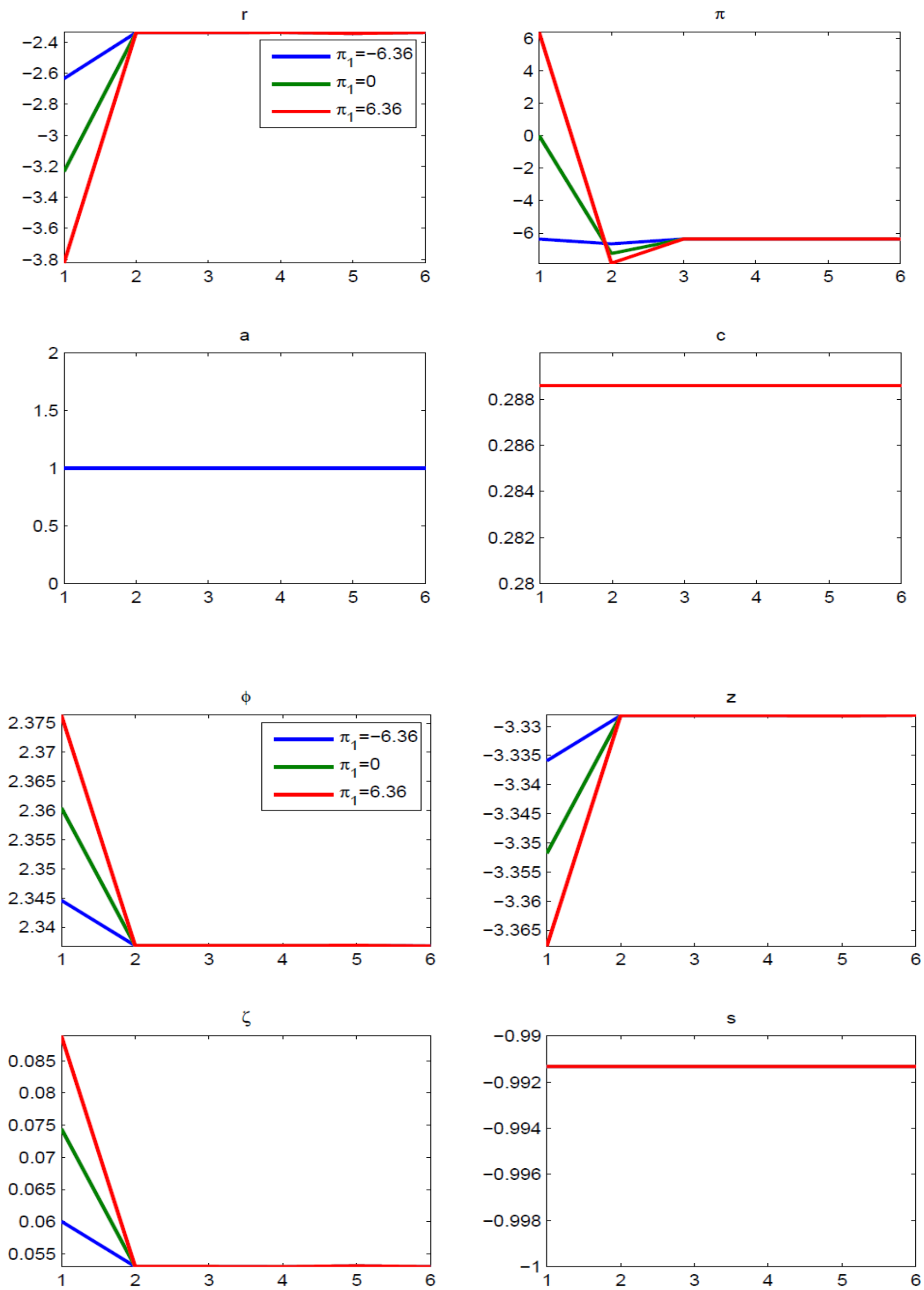


Figure 5: Impulse responses to a permanent technology shock under the Ramsey policy, when $R^l = 1$.