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DOES BROAD MONEY MATTER FOR INTEREST RATE POLICY?

Abstract

This paper presents a business cycle model with financial intermediation encompassing the conventional New Keynesian model. Households' financial wealth comprises cash and interest bearing deposits. When deposits provide transaction services, real broad money, which is predetermined, affects aggregate demand and has a stabilizing impact. Monetary policy can ensure equilibrium uniqueness if the central bank reacts at least slightly on the real broad money gap. Moreover, if the central bank aims at minimizing a standard loss function, real broad money enters the interest rate reaction function. Thus, money matters if it is defined broadly enough to include all households' financial assets.

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1 Introduction

Which role should be assigned to monetary aggregates in the conduct of monetary policy when interest rates are the central bank's main instruments? Modern business cycle theory, labelled the New Neoclassical Synthesis or New Keynesian Macroeconomics, suggests that monetary aggregates can be neglected for equilibrium determination and, therefore, as indicators for inflation. In this paper we show that this conclusion is not necessarily warranted if a broad concept of money is used. We refine the conventional New Keynesian model by assuming that interest bearing deposits in addition to real balances deliver transaction services. It will be shown that broad money substantially affects the local dynamic behavior of the economy. As a consequence, a central bank should take care of the real broad money gap if it aims at stabilizing the economy even if the influence of money on output and inflation might be quantitatively small.

Motivation This paper is motivated by empirical evidence that money significantly contributes to the prediction of inflation and consumption in the US (see, Koenig, 1990, Estrella and Mishkin, 1997, Stock and Watson, 1999, Meltzer, 1999, Nelson, 2000, Rudebusch and Svensson, 2002) and that this can also be found to be larger for broader aggregates (see, Dotsey et al. 2000). Similar conclusions can be derived from recent analyses of Euro area data finding that real broad money contains independent predictive content for inflation rates (see, Gerlach and Svensson, 2000, Trecroci and Vega, 2000, Altimari, 2001) and reduces uncertainty about output forecasts (see, Coenen et al., 2001). Remarkably, Gerlach and Svensson (2000) even find that a real broad money gap entails more information in this regard than output gap or money growth.[1]

A simple comparison between theoretical analyses and empirical work points to a potential explanation for the apparently opposing conclusions concerning the role of money. Empirical papers regularly use broad monetary aggregates, whereas theoretical models implicitly use base money. In this paper we account for this difference and develop a business cycle model featuring inside and outside money. At the heart of

[1] The latter studies mostly utilize the P^* model (see, e.g., Hallmann et al., 1991, or, von Hagen, 1995) which cannot (directly) be incorporated into business cycle theory, since, as stated by Gerlach and Svensson, 'the microfoundations of the P^* model are not clear'.

our model, we assume that all financial assets held by households provide transaction services such that real wealth (broad money) affects aggregate demand.[2] While its composition and its growth rate can freely be adjusted in every moment, the stock of broad money denominated by the beginning-of-period price level cannot jump; the latter being a characteristic feature of a predetermined state variable. Though, the negligence of money is often justified by the empirical finding that the short-run relation between money and inflation has become unstable at least in the US (e.g., by Friedman and Kuttner, 1996), the importance of broad money for interest rate policy in our model stems from the feature that it is an endogenous state variable. Hence, the role of broad money does neither depend on the magnitude of the wealth effect nor on the stability of money demand.[3]

Before turning to a more detailed discussion of our results, we briefly contrast our approach with related work. A direct effect of money on consumption can be obtained if real balances affect the marginal utility of consumption. Despite that it is presumably theoretically incorrect to specify a model without money, the negligence of money is viewed as a reasonable approximation (McCallum 2001; see, also, Dotsey and Hornstein, 2000, Ireland, 2001, or Woodford, 2002a), as this effect is usually estimated to be very small. In our model, the same conclusion can be drawn if money is identified solely with cash. However, the fact that broad money is predetermined delivers a different wealth effect on aggregate demand that cannot be neglected for equilibrium determination. Other justifications for a central bank to pay attention to money have recently been put forward by Christiano and Rostagno (2001) and Söderström (2001), emphasizing the stabilizing potential of money growth. While the former show that switching to a money growth policy can avoid serious instabilities which can arise for simple interest rate rules, the latter demonstrates that targeting money can improve discretionary interest rate policy.

[2]The importance of wealth effects on aggregate demand is recently stressed by Meltzer (1999). An alternative channel for real wealth to affect consumption and inflation is utilized by Leigh and Wren-Lewis (2000) for an analysis of monetary and fiscal policy interactions in a sticky price model where a positive probability of death allows for a deviation from Ricardian Equivalence.

[3]Evidently, not only money demand but almost any structural relation, for example the consumption euler equation (see, Rotemberg and Woodford, 1997), is affected by disturbances.

Modelling broad money We develop a model with financial intermediation nesting the New Keynesian (NK) model, as, e.g., applied in Clarida et al. (1999) or McCallum and Nelson (2000). In every period, households decide on how to divide their stock of financial wealth in cash and interest bearing deposits held at banks. The outstanding role of broad money for the determination of the equilibrium stems from two properties. First, households are endowed with an initial stock of financial wealth and prices are sticky such that real financial wealth is predetermined. Second, both components of financial wealth , i.e., cash and deposits, are assumed to provide transaction services.[4] Consequently, aggregate demand is increasing in real wealth, which is an endogenous state variable spanning together with exogenous variables the state space of the economy. In contrast, NK models do not exhibit any endogenous state variable.[5] They are typically characterized by, at most, a single asset providing transaction services, i.e., cash, and by a real bond indeterminacy such that the path of real wealth is irrelevant for equilibrium determination.[6] Furthermore, cash is regularly specified as a jump variable containing no additional information than already provided, for example, by inflation or output.

Given that broad money equals financial wealth, the fundamental solution for all endogenous variables depends on the current value of real broad money. This also holds for the monetary policy instrument as long as the central bank is not assumed to follow a non-state contingent rule. Thus, we can definitely conclude that broad money matters in this model. Moreover, the importance of broad money does not rely on the strength of the wealth effect, as real broad money qualitatively affects macroeconomic stability, i.e., the conditions for equilibrium determinacy. The analysis contributes not only to our particular environment, as it is isomorphic to an economy which differs from the NK model only by cash assumed to be predetermined, as, for example, in Vegh (2001) or Buiter (2002).

[4] See Patinkin (1965) or, in more recent contributions, Ireland (1994), Bansal and Coleman (1996), and Canzoneri and Diba (2000) allowing for multiple means of payment.

[5] To be more precisely, this is valid for models abstracting from accumulation of physical capital.

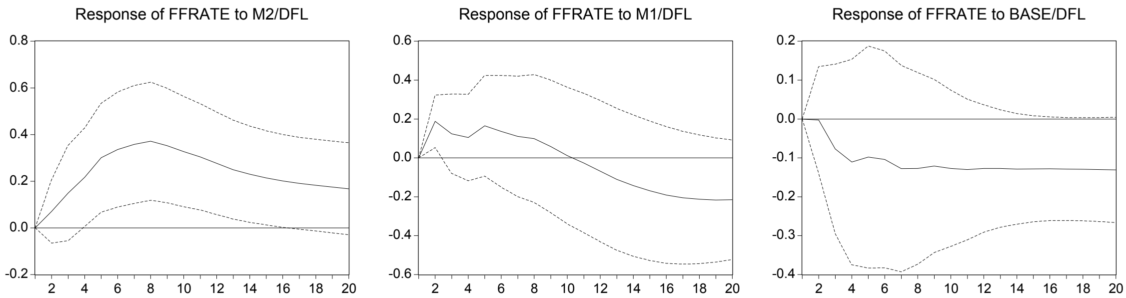
[6] Note that the irrelevance of real wealth is implied by the government solvency constraint satisfied off equilibrium; the latter should generally be guaranteed in this class of models (see, Buiter, 2002).

Macroeconomic stability Consider the case where the central bank sets the nominal interest rate in a passive way such that the real interest rate falls with higher inflation. In this case, the NK model predicts a downward sloping consumption path, which is only consistent with convergence back to the steady state, if current consumption jumps upwards and, therefore, feeds higher inflation. Thus, this environment allows for self-fulfilling inflation expectations unless the central bank raises the nominal interest rate by more than one for one (actively) to changes in inflation (see, e.g., Clarida et al., 1999, or Woodford, 2001). In our model the role of real broad money changes this story. Assume that a non-fundamental shock causes agents to expect higher inflation. For such a sunspot event to induce real effects, output must jump in a consistent way to ensure that the economy will return to the long-run equilibrium. While the NK model imposes no further restriction, in our model a given value of real broad money is only compatible with a certain relation between output, inflation and the nominal interest rate in equilibrium. Hence, the fact that broad money is predetermined precludes multiplicity of equilibrium paths in this case such that sunspot equilibria cannot occur.

Turning to a simple active interest rate rule, our model exhibits no stable equilibrium path. Recall that consumption growth is positively related to the real interest rate. The NK model exhibits a unique stable equilibrium paths where a higher nominal and real interest rate causes consumption immediately to decline and to converge back to its steady state value from below. In our model, a higher nominal interest rate can only be consistent with a given amount of broad money if output is above steady state. Hence, an equilibrium candidate would lead to an explosive behavior for positive consumption growth.[7] This can easily be avoided if the central bank reacts to the real broad money gap. The future decline in broad money, induced by higher nominal interest rates and inflation, will then lead to a decline in the real interest rate reducing aggregate demand and causing forward looking price setters not to feed higher inflation. This stabilizing mechanism only requires very small responses of the nominal interest rate to real broad money.

[7] This result corresponds to findings in Benhabib et al. (2001) and Dupor (2001), showing that activeness can lead to unstable equilibria when an additional productive asset, i.e., money in the production function or physical capital, respectively, is introduced.

Figure 1 Responses of $FFRATE$ to one s.d. innovation of real monetary aggregates



The VARs are estimated with quarterly U.S. data over the period 1962:1–1999:1. All variables are seasonally adjusted and, with the exception of rates, logged. The set of included variables contains real GDP in prices of 1992 (GDP_92), the GDP deflator (DFL), and the producer price index of raw materials (PPI_RAW), the federal funds rate ($FFRATE$), and the base ($BASE$), M1 ($M1$) or M2 ($M2$) as a monetary aggregate denominated with the GDP deflator. The VARs contain five variables in the order: (GDP_92, DFL, PPI_RAW, $FFRATE$, A), with the real monetary aggregate $A \in \{M2/DFL, M1/DFL, BASE/DFL\}$.

The model's implications concerning macroeconomic stability are seemingly at odds with empirical evidence as one frequently finds estimated interest rate policies to be active (see, e.g., Clarida et al., 2000), but not featuring a broad monetary aggregate. However, this evidence can actually be consistent with our theoretical results as long as interest rate policy reacts at least to one endogenous variable and, therefore, implicitly to the endogenous states. Rather then providing another interest rate rule estimation, a straightforward reexamination of a widely-accepted vector autoregression (VAR) should enlighten this argument. Figure 1 displays the impulse responses of the monetary policy instrument, i.e., the federal funds rate, to an innovation to real monetary aggregates derived from VARs estimated with US data using the identification scheme of Christiano et al. (1999). The point estimates indicate that an innovation to real money, identified with M1 or M2 denominated with the GDP deflator, causes a rise in the federal funds rate ($FFRATE$), the policy instrument, which is persistently significant for real M2 ($M2/DFL$) and short-lived for real M1 ($M1/DFL$) shocks. In accordance with our theoretical arguments, shocks to the real monetary base have no significant effects on the federal funds rate. Thus, real broad money significantly affects the nominal interest rate, even if it is not directly targeted by the central bank.[8]

Optimal policy In the last part of the paper we address the issue of optimal interest rate policy. For this, we follow the approach of Svensson (1997) and Clarida et al.

[8]The latter is undoubtedly the case for the Federal Reserve, except for the period 1979-1982.

(1999) and apply a loss function, assumed to be quadratic in inflation and output gap variances, as an objective for optimal monetary policy. The first order condition for the optimal allocation, also known as a targeting rule (see, Svensson, 2001), is shown to be identical to the one commonly derived in NK models. Nevertheless, when a central bank commits itself to this targeting rule, the solution for all endogenous variables, including the nominal interest rate, depends on the particular structure of the model. In our model, the optimal reaction function for the nominal interest rate depends on the real broad money gap.[9] The optimal allocation is found to be associated with an unique equilibrium path in our model, whereas in the NK model the instrument rule demands further restrictions in order to be able to uniquely implement the targeting rule (see, Svensson and Woodford, 1999, or Giannoni and Woodford, 2002). Simulated losses for optimal interest rate reaction functions derived in both models indicate that the negligence of real broad money has substantial effects on cyclical fluctuations. Again, this holds regardless of the magnitude of the wealth effect.

The remainder is organized as follows. The model is developed in section 2. The long-run equilibrium and the conditions for macroeconomic stability for two versions of the model are give in section 3. Section 4 discusses the implications for optimal policy rules. Section 5 concludes.

2 The model

In this section we develop a business cycle model with staggered price setting and financial intermediation. Households divide their stock of financial wealth, which is predetermined at the beginning of each period, into cash and deposits. Both assets in real terms enter the utility function as a proxy for assuming that they provide transaction services.[10] Perfectly competitive banks are assumed to invest the deposited funds in government liabilities and corporate debt. The latter are issued by perfectly competitive firms facing a liquidity constraint which demands that wages must be

[9] These solutions are expressed as functions of endogenous and exogenous states which are assumed to lie in the information set of the central bank (see, e.g., Svensson, 2001) and, therefore, differ, for example, from the forward looking specification in Clarida et al. (1999).

[10] See Feenstra (1986) for the equivalence between cash-in-advance and money-in-utility assumptions.

paid in advance. To avoid interactions of the dynamic decisions concerned with bonds issuance and staggered price setting, we introduce a retail sector (see, Bernanke et al. 1999). Monopolistically competitive retailer purchase the wholesale goods produced by the firms and sell them with a mark-up to the household sector, subject to a stochastic nominal price rigidity allowing them to adjust the final goods prices only occasionally. The banks hold a minimum amount of reserves with can either be interpreted as a reserve requirement on bank deposits or a buffer stock of reserves held for stochastic withdrawals caused by shocks not explicitly considered in this model. Hence, financial intermediaries transform bonds together with reserves into inside money.

Households Nominal variables are denoted by upper-case letters, while real variables are denoted by lower-case letters. There is a continuum of households $j \in (0,1)$. They are identically except for their specific labor endowment l_j, which they supply monopolistically in the labor market. Using that the non-labor decisions are identical between all households, we simplify the analysis by deriving the optimal non-labor decisions for a representative household. The indexation of households' variables with j is, therefore, dropped except for labor market variables. The objective of household j is given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t u\left(c_t, 1-l_{jt}, m_t^h, d_t\right), \text{ with } \beta \in (0,1), \tag{1}$$

where β denotes the discount factor. As can be seen from the objective in (1), instantaneous utility $u(.)$ depends on consumption c, leisure $1-l_j$, and real balances $m_t^h \equiv M_t^h/P_t$ as well as real deposits $d_t \equiv D_t/P_t$, where M^h denotes cash and D the deposits in nominal terms and P the aggregate price level. Assumption 1 summarizes the properties of the utility function.

Assumption 1 *The utility function $u(c_t, 1-l_{jt}, m_t^h, d_t)$ is increasing, concave and twice continuously differentiable with $u_c, u_l \equiv \partial u/\partial(1-l), u_m \equiv \partial u/\partial m^h > 0$ and $u_d \geq 0$; $u_{cc}, u_{ll}, u_{mm} < 0$ and $u_{dd} \leq 0$; satisfies i) the usual inada conditions for $c_t, 1-l_{jt}$,* and *m_t^h, ii) $u_{xy} = 0$ for $x \neq y$ with $x, y \in \{c_t, 1-l_{jt}, m_t^h, d_t\}$.*

Note that employment l is constrained by $0 \leq l < 1$. Two properties of the utility function stated in assumption 1 demand some attention. First, we impose that the utility function is separable with regard to all arguments. This restriction is not just introduced to simplify the calculations, but it also allows to isolate a novel channel which causes money to matter. As recently stressed by Ireland (2001), non-separability of the utility function can be sufficient to obtain a non-negligible role of the respective monetary aggregate. In order to switch this channel off we, therefore, decided to apply a separable utility function. Moreover, even though separability between consumption and money might be theoretically not very satisfactory, empirical evidence indicates that it can be regarded as a valid approximation (see, Ireland, 2001, McCallum, 2001, Woodford, 2002a).

Second, deposits may enter the utility function. We allow for marginal utility of deposits to be zero in order to encompass the conventional New Keynesian model in our framework. However, our new results concerning the role of broad money are derived for utility being strictly concave in real deposit holdings. This crucial assumption is introduced as a short-cut for modelling the ability of deposits to provide transactions services. We perceive this assumption as probably more realistic than to restrain that only cash provide transaction services, as the former asset also reduces transaction costs either, directly, due to their usage as a means of payment or, indirectly, because of its acceptance as collateral. Accordingly, this assumption might possibly be extended to all, at least risk-free, financial assets of households. To give a preview, this assumption allows to determine the stock of real broad money and, therefore, real wealth, in equilibrium. Clearly, this is impossible in an environment where non-cash assets are not linked to the remaining variables in the model (see also Canzoneri and Diba, 2000).[11]

In each period households decide, after shocks occurred, on how to divide the predetermined stock of financial wealth A in holdings of money and deposits ($A_t = M_t^h + D_t$), associated with interest earnings equal to $i_t^d D_t$. Each household owns an identical share of all productive and financial firms in the economy. Accordingly, profits earned by banks, firms, and retailers are transferred to the households. Moreover, he receives wage payments and a government transfer. The household's budget constraint

[11] As a minor remark, it should be noted that we implicitly assume that asset markets open after shocks occur, but close before goods market open. As recently stressed by Carlstrom and Fuerst (2001), our timing might be preferable as it is consistent with conventional cash-in-advance constraints.

is given by

$$A_{t+1} = (1+i_t^d)A_t - i_t^d M_t^h + P_t w_{jt} l_{jt} - P_t c_t + P_t \tau_t + P_t \Omega_t^b + P_t \Omega_t^f + P_t \Omega_t^r, \quad (2)$$

where w_j denotes the real wage for l_j, τ the real government transfer, and Ω^b, Ω^f, and Ω_t^r real profits of banks, firms, and retailers. Maximizing the objective given in (1) subject to the budget constraint (2), a no-ponzi-game condition for a given initial value of total nominal wealth A_0, leads to the following first order conditions for consumption, money and financial wealth:

$$\lambda_t = \frac{\partial u}{\partial c_t}, \quad (3)$$

$$\lambda_t i_t^d = \frac{\partial u}{\partial m_t} - \frac{\partial u}{\partial d_t}, \quad (4)$$

$$\frac{\lambda_t}{\beta} = E_t \left[\frac{\partial u}{\partial d_{t+1}} \frac{1}{\pi_{t+1}} \right] + E_t \left[\lambda_{t+1} \frac{1+i_{t+1}^d}{\pi_{t+1}} \right], \quad (5)$$

where λ denotes the Lagrange multiplier for the budget constraint (2) and $\pi_{t+1} = \frac{P_{t+1}}{P_t}$ the gross inflation rate. The first order conditions for cash and financial wealth (4)-(5) will play a crucial role in the subsequent analysis. Though, (5) is somehow similar to the conventional first order condition on bonds, it differs with regard to the marginal utility of deposits. As it will be shown in the remainder of this paper, this is the main source for broad money to affect the local dynamics of the economy. In the optimum the budget constraint (2) and the transversality condition

$$\lim_{i \to \infty} \lambda_{t+i} \beta^{t+i} \frac{A_{t+i}}{P_{t+i}} = 0 \quad (6)$$

must also be satisfied; the latter providing a terminal condition for the households' intertemporal behavior. We assume that households monopolistically supply differentiated labor services as in Erceg et al. (2000). Perfectly competitive units/firms transform the differentiated labor services l_j into one type of labor input l, which can be employed for the production the final good. The transformation is conducted via the aggregator:

$$l_t = \left[\int_0^1 l_{jt}^{\frac{\eta_t - 1}{\eta_t}} di \right]^{\frac{\eta_t}{\eta_t - 1}}, \text{ with } \eta_t > 1, \quad (7)$$

where η_t is the elasticity of substitution between differentiated labor services. Departing from the common specification, we will allow the elasticity η_t to vary (exogenously) over time. Such variations can be interpreted as changes in the competitiveness of the labor market lying outside the endogenous decisions considered in the model.[12] When labor aggregating units minimize costs with respect to differentiated labor services we obtain the following demand schedule for l_j:

$$l_{jt} = \left(\frac{w_{jt}}{w_t}\right)^{-\eta_t} l_t, \qquad \text{with} \qquad w_t = \left[\int_0^1 w_{jt}^{(1-\eta_t)} dj\right]^{\frac{1}{1-\eta_t}}, \tag{8}$$

where w denotes the wage rate for the aggregate labor services l. Given the demand function for differentiated labor services (8), utility maximization implies the following optimal supply condition for aggregate labor services

$$w_t = \frac{u_{lt}}{u_{ct}} \mu_t, \tag{9}$$

where μ_t denotes the markup over the perfectly competitive real wage $\mu_t = \frac{\eta_t}{\eta_t - 1}$. When the markup equals one ($\mu_t = 1$) the labor supply condition in (9) resembles the case of a perfectly competitive labor market. Introducing the stochastic element, we assume that the mark-up μ evolves according to the following stationary first order autoregressive process:

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + (1 - \rho_\mu) \log \overline{\mu} + \varepsilon_{\mu t}, \quad \text{with } 0 \leq \rho_\mu < 1 \text{ and } \varepsilon_{\mu t} \sim N(0, \sigma_\mu^2). \tag{10}$$

where $\overline{\mu}$ denotes the steady state value, the autoregressive parameter ρ_μ is smaller than one and the innovations ε_μ are i.i.d.. Allowing for exogenous changes in the mark-up, the model provides a source for shocks raising the costs of final goods producing firms, the so-called cost-push shocks, which will be essential in the analysis of optimal monetary policy.

Financial Intermediation Intermediaries are assumed to be perfectly competitive. They take deposits from households paying a nominal return i^d. These deposited funds D are invested in government liabilities, i.e., money M^b and bonds B^b, and in corporate bonds B^c. In each period profits Ω_t^b are transferred to households being the owners

[12] For example, a decline in η_t leads to an exogenous increase in the competitiveness reducing the market power of the supply side.

of the intermediaries. The flow budget constraint of a representative intermediary is given by

$$D_{t+1} - (1+i_t^d)D_t = B_{t+1}^b - (1+i_t)B_t^b + B_{t+1}^c - (1+i_t^c)B_t^c + M_{t+1}^b - M_t^b + P_t\Omega_t^b, \quad (11)$$

where i (i^c) denotes the nominal interest rate on government (corporate) bonds. We assume that the central bank imposes a minimum reserve requirement on deposits which is aimed to ensure the liquidity in the intermediary sector. To put this regulatory measure in the context of the model's feature that deposits provide transaction services, we implicitly assume that agents perceive the fulfillment of the reserve requirement as a prerequisite for accepting deposits as a means of payment. The reserve requirement on deposits is governed by a constant rate θ, with $0 \leq \theta < 1$:

$$M_t^b \geq \theta D_t. \quad (12)$$

Actually, there is no endogenous justification for cash holdings of financial intermediaries. Though, in several countries reserve requirements are already eliminated, they still play a non-negligible role in the conduct of monetary policy in several countries. However, cash holdings of financial intermediaries can also be rationalized without relying on such a regulation. For example, banks can voluntarily hold a certain amount of reserves to be prepared for unexpected withdrawals.[13] We further impose that the intermediary must be asymptotically solvent:

$$\lim_{j\to\infty} \left(B_{t+j}^c + B_{t+j}^b + M_{t+j}^b - D_{t+j}\right) E_t \prod_{v=1}^{j} (1+i_{t+v})^{-1} \geq 0. \quad (13)$$

We assume that intermediaries maximize the present discounted value of future stream of real profits weighted by the marginal utility of consumption because each intermediary is owned by the households. The banks maximization problem is constrained by

[13] This could, for example, be implemented by considering events, which induce households to withdraw their intermediated funds and do not interact with other economic decisions of agents, occurring with a probability θ (see Shreft and Smith, 2000).

the definition of the profits in (11) and the minimum reserve requirement in (12):

$$\max E_t \sum_{s=0}^{\infty} \left\{ \beta^t \frac{\lambda_{t+s}}{\lambda_t} \Omega^b_{t+s} \right\} \quad \text{s.t. (11) and (12).} \tag{14}$$

As we assumed that financial intermediaries are perfectly competitive, they take the interest rates on bonds and deposits as given. The first order conditions for money, bonds, and deposit holdings are then given by:

$$i^d_t = i_t(1-\theta), \tag{15}$$

$$\psi_t(M^b_t - \theta D_t) = 0, \quad \psi_t \geq 0, \quad M^b_t - \theta D_t \geq 0, \tag{16}$$

$$E_t\left[\frac{1+i_{t+1}}{\pi_{t+1}}\lambda_{t+1}\right] = \frac{1}{\beta}\lambda_t, \tag{17}$$

$$E_t\left[\frac{1+i^c_{t+1}}{\pi_{t+1}}\lambda_{t+1}\right] = E_t\left[\frac{1+i_{t+1}}{\pi_{t+1}}\lambda_{t+1}\right], \tag{18}$$

$$E_t\left[\lambda_{t+1} i_{t+1}\right] = \psi_t, \tag{19}$$

and the solvency constraint (13) holding with equality. The variable ψ denotes the Kuhn-Tucker multiplier referring to the minimum reserve requirement (12). With positive values of λ and the central bank setting a strictly positive nominal interest rate (see below), it can be seen from (16) and (19) that the minimum reserve requirement will be binding in equilibrium: $M^b_t = \theta D_t$.

Production sector A continuum of identical and perfectly competitive firms produce the wholesale good y^w using a technology which is linear in the aggregate labor input:

$$y^w_t = l_t. \tag{20}$$

In order to provide a reasonable purpose for corporate debt, the firms are assumed to face a liquidity constraint which demands that the wage bill should be paid in advance. They meet this financial demand by the issuance of bonds B^c:

$$B^c_t \geq w_t l_t. \tag{21}$$

Firms sell the wholesale good to retailers at a competitive price P^w, and hire the aggregate labor input at the economy wide price level P, which will be defined below. Hence, firms' profits Ω^f_t, which are lump-sum transferred to the owners (households), are implicitly given by the following budget constraint of a representative firm

$$B_{t+1}^{c}+P_{t}^{w}y_{t}^{w}=(1+i_{t}^{c})B_{t}^{c}+P_{t}w_{t}l_{t}+P_{t}\Omega_{t}^{f}. \tag{22}$$

For the remainder of this paper it is convenient to define a mark-up of the economy wide price level P over the wholesale price: $\mu_{Pt}=P_{t}/P_{t}^{w}$. Firms are further restricted to be asymptotically solvent :

$$\lim_{j\to\infty}B_{t+j}^{c}E_{t}\prod_{v=1}^{j}(1+i_{t+v})^{-1}\leq 0. \tag{23}$$

The firms are assumed to maximize the present discounted value of future stream of real profits weighted by the marginal utility of consumption subject to the liquidity constraint (21) and its budget constraint (22)

$$\max E_{s}\sum_{t=0}^{\infty}\left\{\beta^{t}\frac{\lambda_{s+t}}{\lambda_{s}}\Omega_{s+t}^{f}\right\}\quad\text{s.t.}\quad(22)\quad\text{and}\quad(21),$$

delivering the following first order conditions for labor demand and for the issuance of corporate bonds:

$$w_{t}\left(1+\delta_{t}\right)=mc_{t}, \tag{24}$$

$$E_{t}\left[\left(\frac{1+i_{t+1}^{c}}{\pi_{t+1}}-\delta_{t+1}\right)\lambda_{t+1}\right]=\frac{1}{\beta}\lambda_{t}, \tag{25}$$

$$\delta_{t}(B_{t}^{c}-P_{t}w_{t}l_{t})=0,\quad\delta_{t}\geq 0,\qquad B_{t}^{c}-P_{t}w_{t}l_{t}\geq 0, \tag{26}$$

where the real marginal costs of a firm mc is the inverse of the mark-up μ_{p} : $mc_{t}=1/\mu_{pt}$. Furthermore, the solvency constraint (23) holds with equality in the firm's optimum. It can immediately be seen from the firms' first order condition for bonds (25) and from the banks' optimal demand for corporate bonds (17), that the Kuhn-Tucker multiplier on the liquidity constraint δ will be equal to zero in equilibrium. Hence, the labor demand condition (24) will, therefore, take a conventional form, $w_{t}=mc_{t}$, in equilibrium.

Retail sector The final consumption good is an aggregate of a continuum of differentiated goods supplied by monopolistically competitive retailer indexed with $i\in(0,1)$. They buy the wholesale good from the production sector. After the wholesale good is differentiated, a retailer i sells an amount y_i of differentiated goods charging an individual price P_i with the mark-up μ_{ip}. The final good y is obtained by a CES aggregator of the differentiated goods, which is similar to the aggregator in (7):

$$y_t = \left[\int_0^1 y_{it}^{\frac{(\epsilon-1)}{\epsilon}} di \right]^{\frac{\epsilon}{\epsilon-1}}, \text{ with } \epsilon > 1, \tag{27}$$

where y is the number of units of the final good, y_i the amount sold by retailer i, and ϵ the constant elasticity of substitution between these differentiated goods. Let P_i and P denote the price of good i set by retailer i and the price index for the final good. The demand for each differentiated good is derived by minimizing the total costs of obtaining y subject to (27), analogous to the labor demand condition (8): $y_{it} = (P_{it}/P_t)^{-\epsilon} y_t$, with $P_t^{(1-\epsilon)} = \int_0^1 P_{it}^{(1-\epsilon)} di$.

We introduce a nominal rigidity in form of staggered price setting as developed by Calvo (1983). In each period, retailer may reset their prices with the probability $1-\phi$ independent of the time elapsed since the last price setting. The fraction ϕ of retailer are assumed to adjust their previous period's prices according to the following simple rule: $P_{it} = \overline{\pi} P_{it-1}$, where $\overline{\pi}$ denotes the average of the inflation rate $\pi_t = P_t/P_{t-1}$. The derivation of the first order condition of the price setters is provided in appendix 6.1. The linear approximation of the corresponding aggregate supply constraint at a stationary state is given by

$$\widehat{\pi}_t = \chi \widehat{mc} + \beta E_t[\widehat{\pi}_{t+1}], \text{ with } \chi = (1-\phi)(1-\beta\phi)\phi^{-1}, \tag{28}$$

where $\widehat{x}$ denotes the percent deviation from the steady state value $\overline{x} : \widehat{x} = \log(x_t) - \log(\overline{x})$. This forward looking optimal pricing schedule, which is commonly applied in monetary business cycle models, is also known as the 'New Keynesian Phillips' curve.

Public sector The public sector consists of two parts, the monetary authority and the fiscal authority. The fiscal authority receives funds by issuing one period risk-free bonds which pay an interest rate i. It uses lump-sum transfers to balance the flow budget constraint after the monetary authority transfers receipts from money creation. The consolidated budget constraint is given by

$$B_{t+1} + M_{t+1} = (1+i_t)B_t + M_t + P_t\tau_t,$$

We further demand the monetary and fiscal policy regime to satisfy the following solvency constraint written in terms of total government liabilities, $S_t = M_t + B_t$:

$$\lim_{i\to\infty} S_{t+i} E_t \prod_{v=1}^{i} (1 + i_{t+v})^{-1} = 0. \tag{29}$$

In the recent literature (see, e.g., Benhabib et al., 2001, or Buiter, 2002) such a policy regime is also called Ricardian.

The monetary authority is assumed to control the short-run nominal interest rate on government bonds i. It sets a stationary sequence for the gross short run nominal interest rate $\{R\}_{t=0}^{\infty}$ where R_t is defined as $R_t \equiv 1 + i_t > 1$ $\forall t$. In the subsequent analysis we introduce several forms of monetary policy rules where the interest rate is allowed to be set contingent on endogenous variables ('instrument rules'). We further derive interest rate rules, which support loss function minimizing plans ('targeting rules'), as functions of endogenous and exogenous state variables.

Rational expectation equilibrium Markets for labor, assets, and goods clear in equilibrium. The state space is spanned by the exogenous state variable μ_t and the single endogenous state variable $a_t = A_t/P_{t-1}$.

Definition 1 *Given the initial stock of households' financial wealth A_1, the initial price level P_0 and the process for the exogenous state* (10)*, a rational expectation equilibrium is an allocation* $\{c_t(a_t, \mu_t), l_t(a_t, \mu_t), m_t^h(a_t, \mu_t), m_t^b(a_t, \mu_t), m_t(a_t, \mu_t), d_t(a_t, \mu_t), b_t^c(a_t, \mu_t), b_t(a_t, \mu_t), y_t(a_t, \mu_t), a_{t+1}(a_t, \mu_t)\}_{t=0}^{\infty}$*, and a set of sequences for prices and costates* $\{w_t(a_t, \mu_t), \pi_t(a_t, \mu_t), \psi_t(a_t, \mu_t), \delta_t(a_t, \mu_t), \lambda_t(a_t, \mu_t), i_t^d(a_t, \mu_t), i_t^c(a_t, \mu_t), mc_t(a_t, \mu_t), R_t(a_t, \mu_t)\}_{t=0}^{\infty}$ *satisfying*

- *the households' first order conditions* (3)-(5) *and* (9)*,*
- *the firms' first order conditions* $(24) - (26)$*, the aggregate production function* $(y_t = l_t)$*, and the solvency constraint* (23) *holding with equality,*
- *the aggregate supply constraint* (28)*,*
- *the banks' first order conditions* (15)-(19) *and the solvency constraint holding with equality* (13)*,*
- *the interest rate policy $R_t(a_t, \mu_t)$ with $E_0(R_t) = \bar{R}$ and $R_t - 1 > 0$ $\forall t$ and the government solvency constraint* (29)*,*
- *markets for money $(M_t = M_t^h + M_t^b)$ and goods $(P_t y_t = P_t c_t)$ clear,*

- *and the transversality condition* (6).

Using that the reserve requirement is binding as λ_t and i_t are always strictly larger than zero, the first order conditions (16) and (18) can be combined to a binding reserve requirement: $M_t = \theta D_t$. Hence, the equilibrium values of all assets can be determined, except for bonds. The latter property, which is also known as 'real bonds indeterminacy' (Canzoneri and Diba, 2000), is in common with conventional business cycle models where the policy regime is solvent, implying a 'debt neutrality' (see, also, Buiter, 2002).

Further, it should be noted that the transversality condition (6) and the government solvency constraint (29) do not coincide in equilibrium. This feature, which stands in contrast to a respective identity, e.g., in NK models, comes from the fact that financial wealth generally differs from the stock of government liabilities because banks also hold corporate bonds. Nevertheless, since public policy as well as banks' and firms' behavior is assumed to satisfy the solvency constraints (13), (23), and (29), the paths of the fiscal policy instruments, i.e., lump-sum transfers and bond issuance, do not matter for equilibrium determination.

3 Instrument rules and macroeconomic stability

In this section, we focus on the implications of interest rate setting on macroeconomic stability. To be more precisely, we are interested in the conditions for instrument rules to ensure a unique rational expectation equilibrium path. As indeterminate equilibria allow for fluctuations due to non-fundamental phenomena, equilibrium determinacy can be interpreted as a prerequisite for optimal monetary policies. In order to facilitate comparisons with the existing literature, we make use of the fact that the model nests the NK model as a special case.

Two versions of the model In monetary business cycle models, deposits are commonly not explicitly considered. This can be resembled in our model if the utility function is independent of real deposit holdings ($u_d, u_{dd} = 0$) and if banks are not restricted by a reserve requirement ($\theta = 0$). Under these specific assumptions, deposits equals bonds and do not affect any other variable in equilibrium (see below). In the remainder of the paper we will call this the C model as a mnemonic for the property that this version is equivalent to a Conventional New Keynesian model. As the dynamic properties of the C model are already elaborately analyzed (see, e.g., Woodford, 2002b) in the literature, we are primarily interested in the case where deposits do provide transaction services (hence, $u_d > 0$ and $u_{dd} < 0$) while a minimum liquidity in the banking sector is assured by a strictly positive reserve requirement ($\theta > 0$). We will call this the B version of the model referring to the property that real Broad money affects the remaining variables in equilibrium.

Definition 2 *The B version (C version) of the model is characterized by a rational expectations equilibrium given in definition 1 and by θ, $u_d > 0$ and $u_{dd} < 0$ (θ, u_d, $u_{dd} = 0$).*

The crucial difference between these two versions is that the equilibrium value of real deposits is linked to the remaining variables in the B model, whereas its equilibrium value cannot be determined in the C model. It might be worth mentioning that the distinction between the two versions does not depend on the degree in which deposits help to facilitate transactions. Hence, the B version is valid even if the marginal utility of deposits becomes very small. In other words, the C version cannot be interpreted as a limiting case of the B model in which $\lim u_d \to 0$. Given that the equilibrium values of both deposits and government bonds cannot be pinned down in the C model, this version exhibits a real broad money indeterminacy and, therefore, also a real wealth indeterminacy. Thus, a unique equilibrium in the C model is compatible with multiple sequences for real financial wealth. In contrast, both components of real broad money affect the consumption path in the B model, as can be seen from the households first order conditions (4) and (5). Nevertheless, our model predicts that output and inflation are independent of monetary aggregates in the long run equilibrium. The main long run properties of both versions are summarized in the following proposition.

Proposition 1 *Given that the interest rate policy is stationary, the long run equilibrium*

1. *in both versions of the model is characterized by i) unique stationary values of output, production, consumption and wages which are independent of monetary policy, ii) unique stationary values of inflation, real balances and interest rates*

for deposits, and iii) a steady state inflation rate rising in the stationary value of the nominal interest rate, while

2. *in the B version the long run equilibrium is further characterized by i) unique stationary values for real deposits, real reserves and real broad money, and by ii) real deposits, its interest rate and real broad money as decreasing functions of the reserve requirement ratio θ, and reserves increasing in θ if $-\frac{u_{dd}d}{u_d} > 1$.*

Proof. See appendix 6.2. ■

Hence, the long run properties of both versions of the model are identical with respect to output and inflation. It should be emphasized that 1i) holds regardless of the restrictions on interest rate policy. Furthermore, the B model predicts that real broad money declines when the monetary stance is permanently tightened by a rise in the reserve requirement ratio θ. In common with the NK model, a permanent rise in the nominal interest rate just raises the stationary inflation rate in both versions of our model. The fact that permanent changes in the stock of broad money leaves output and inflation unaffected will be exploited in the following. In particular, the linear approximation of the model at the long run equilibrium provides a framework in which the B model differs from the C version just with regard to one static equilibrium condition.

Local dynamics of the linearized model In the remainder of this section, we investigate the restrictions on monetary policy which guarantee the existence of a unique and stable equilibrium. We consider interest rate policies in form of instrument rules, i.e., we assume that the nominal interest rate on government bonds is a 'simple function of a small subset of the information available to the central bank' (see, Svensson, 2001). The local dynamic properties of the model are analyzed for a utility function satisfying assumption 1 with constant elasticities of substitution, i.e., $\frac{u_x}{u_{xx}x} = -\frac{1}{\sigma_x}$, with $\sigma_x \geq 1$ for $x = c, 1-l, m^h$, and in the B version also for $x = d$. We further assume that elasticity of substitution for both assets is identical ($\sigma_m = \sigma_d = \sigma$). Linearizing the equilibrium conditions at the steady state leads to the following three equations for the B model (see appendix 6.3) governing the rational expectations equilibrium paths for inflation, output and real broad money:[14]

$$\widehat{y}_t = E_t\widehat{y}_{t+1} + \frac{1}{\sigma_c}E_t\widehat{\pi}_{t+1} - \frac{1}{\sigma_c}E_t\widehat{R}_{t+1}, \tag{30}$$

$$\widehat{\pi}_t = \beta E_t\widehat{\pi}_{t+1} + \gamma\widehat{y}_t + \chi\widehat{\mu}_t, \tag{31}$$

$$\widehat{a}_t = \widehat{\pi}_t + \frac{\sigma_c}{\sigma}\widehat{y}_t - \frac{1}{\sigma}\frac{\bar{R}}{\bar{R}-1}\widehat{R}_t. \tag{32}$$

The C model consists just of the first two equations, the so-called forward looking IS curve and the New Keynesian Phillips curve. This can immediately be seen from the first order conditions for deposits and bonds being identical for $\theta, u_d, u_{dd} = 0$ (see equation 5 and 17) and by recalling that real bonds are always indetermined. Therefore, equation (32), which is derived from the first order conditions of money deposits and bonds (4), (5), and (17), just enters the B model. It provides an equilibrium condition relating real broad money holdings to current values of output and the nominal interest rate on bonds. Noticing that real broad money a_t is already given at the beginning of period t, it can be interpreted as households willing to raise consumption when their real broad money holdings exceed the steady state value. This effect is even more pronounced for higher nominal interest rates, as this raises the opportunity cost of non-bond assets and, therefore, reduces the willingness to hold broad money. It should further be noted that broad money is denominated in the previous period price level, $a_t = A_t/P_{t-1}$, such that a decline in inflation works expansionary because it leads to a rise in the current period real value of broad money, A_t/P_t, which actually reduces transaction costs.

On a first sight, the equilibrium condition on real broad money resembles a conventional first order condition for cash. However, the first two equations cannot be separated from this contemporaneous wealth equation, since real broad money $a_t = A_t/P_{t-1}$ is a predetermined state variable in this model. This points at a crucial difference between narrow and broad money. Narrow money (cash) is a jump variable in the model such that one can separately solve for its equilibrium path.[15] Hence, we

[14] The parameter γ is defined as: $\gamma = \chi\omega_1$, with $\omega_1 \equiv (\sigma_n \frac{\bar{l}}{1-\bar{l}} + \sigma_c)$.

[15] Note, however, that money could in principle also be treated as an predetermined variable. More excactly, this would require the very special assumption that asset markets open after good markets close given that beginning-of-period real balances enter the utility function.

can ignore cash holdings for an analysis of inflation and output. Evidently, real financial wealth is always predetermined. The difference between both models is that real financial wealth, which equals real broad money, is linked to the remaining variables (π, y) in the B model, whereas it is irrelevant for the determination of the equilibrium in the C model. Consequently, in the latter model there is no analogue to the equilibrium condition for real financial wealth (32). The following proposition summarizes the local dynamic properties of the C model with a state-contingent instrument rule featuring future inflation as the single argument.

Proposition 2 *In the C model given by (30) and (31) with an interest rate policy described by $\widehat{R}_t = \rho_\pi \widehat{\pi}_t$, there exists a unique rational expectation equilibrium path converging to the steady state of the economy iff*

$$1 < \rho_\pi < 1 + 2\,(1+\beta)\,\frac{\sigma_c}{\gamma}. \tag{33}$$

If (33) does not hold, there exists a continuum of equilibrium paths converging to the steady state.

Proof. See appendix 6.4 or Woodford (2002b). ■

The properties of the C model summarized in proposition 2 are clearly not new and correspond to the results in Carlstrom and Fuerst (2001) and Woodford (2002a,b). The main result, the so-called Taylor-principle, is that the C model, which exhibits only jump variables, demands activeness of monetary policy ($\rho_\pi > 1$) in order to rule out multiple rational expectation equilibrium paths. The well-known mechanism, which is responsible for this property, will be briefly described below in a comparison with the determinacy conditions in the B model. The qualification to the Taylor principle, which is inherent in (33), just excludes hyperactive policies as the upper bound on ρ_π is very large for any reasonable parametrization (see also Clarida et al., 1999, or Woodford, 2002b).

Turning to the B model, we now have to consider that real broad money is, by (32), linked to output and inflation such that the model features a non-negligible predetermined endogenous state variable changing the conditions for interest rate rules to ensure equilibrium determinacy. While activeness is necessary for equilibrium uniqueness in the C model, this is not valid in the B model, where indeed passive rules are associated with determinacy and activeness destabilizes the economy. In this case, a uniquely determined stable equilibrium can be restored if the central bank also reacts to changes in the stock of real broad money when setting its instrument. In this respect, reacting to the real broad money gap might help stabilizing the economy. Our findings are presented more formally in the following proposition.

Proposition 3 *In the B model given by (30) to (32) with an interest rate policy described by*

$$\widehat{R}_t = \rho_\pi \widehat{\pi}_t + \rho_a \widehat{a}_t, \quad \text{with} \quad \rho_\pi, \rho_a > 0,$$

there exists a unique rational expectation equilibrium path converging to the steady state of the economy iff

$$\rho_\pi < 1 + \rho_a \frac{1}{\sigma} \left[\frac{1}{(\bar{R} - 1)} + (\sigma - 1) - \sigma_c \frac{1 - \beta}{\gamma} \right] \tag{34}$$

$$\text{or } \rho_\pi > 1 + 2(1+\beta)\frac{\sigma_c}{\gamma} + \rho_a \frac{1}{\sigma} \left(\frac{1}{(\bar{R} - 1)} - (\sigma - 1) + \frac{\sigma_c}{\gamma} \frac{\bar{R} + (1+\beta)\left(1 + \bar{R}\right)}{\bar{R} - 1} \right) \tag{35}$$

Proof. See appendix 6.5. ■

Two main conclusions can be drawn from this proposition. First, if a central bank does not react on broad money, it is sufficient for determinacy to set interest rates in a passive way ($\rho_\pi < 1$). Evidently, this implies that an interest rate peg, $R_t = R \; \forall \; t$, is associated with equilibrium determinacy. This result clearly stands in contrast to the conventional view that an interest rate peg leads to indeterminacy. On the other hand, it accords to the results recently derived for modifications of the NK model allowing for productive assets, like physical capital (see, Dupor, 2001) or money in the production function (see, Benhabib et al., 2001). These models further predict, as the B model, that an active interest rate policy ($\rho_\pi > 1$, $\rho_a = 0$) leads to an unstable equilibrium. Note that in our model this feature holds unless policy is hyperactive (see, 35). The second main implication from proposition 3 is concerned with the role of real broad money as an argument of the instrument rule. A further inspection of the determinacy condition reveals that reacting on the real broad money gap increases the likelihood that the equilibrium is determinate for active rules, if the expression in the square brackets in (34) is positive. This finding is summarized in the following corollary.

Corollary 1 *If* $\frac{\beta}{\bar{\pi}-\beta} > \frac{\phi}{1-\phi}$ *then there exists for each interest rate rule with* $\rho_\pi > 1$ *one* $\widetilde{\rho}_a > 0$ *such that any interest rate rule with* $\rho_a > \widetilde{\rho}_a$ *ensures determinacy.*

Proof. See appendix 6.6. ■

It should be noted that the condition stated in corollary 2 is not necessary. But already the sufficient condition will always hold for any reasonable parametrization, as it would be violated only if a very high degree of price stickiness is associated with a very high steady state inflation. Consider, as an example, a rule with $\rho_\pi = 1.5$ as originally proposed by Taylor (1993). Setting the parameter values, listed below in table 1, in accordance with related studies, we arrive at $\widetilde{\rho}_a$ equal to 0.011. Hence, even a small responsiveness of interest rates on deviation in real broad money is sufficient to guarantee the existence of a unique rational expectation equilibrium path.

What are the reasons for the determinacy conditions in proposition 3? We start the discussion with the case of a passive interest rate rule ($\rho_\pi < 1$) which is regularly associated with multiple equilibrium paths in NK models (see, Benhabib et al., 2001, or Woodford, 2001). In the C version inflation expectations can be self-fulfilling, as higher inflation lowers the real interest rate inducing households to postpone savings such that increased aggregate demand causes firms to raise prices. In this case, the C model allows for multiple equilibrium paths such that arbitrary inflation expectations can force the economy out of its long run equilibrium. In the B model the existence of multiple equilibrium paths are ruled out due to the existence of the real broad money condition (32). From all equilibrium sequences that are compatible with (30) and (31) for a passive rule, equation (32) selects the single candidate which is compatible with the predetermined value for real broad money $a_t = A_t/P_{t-1}$. Hence, the B model exhibits unique equilibrium sequences for the triplet (π, y, a).

The economic reason for this stabilizing role of real broad money in the B model stems from the fact that both of its components provide transaction services to the households. A rise in inflation lowers broad money denominated by the current price level $(M_t^h + D_t)/P_t$. In order to satisfy the equilibrium condition (32), output has to jump to a certain amount which, in general, is not identical to the amount needed to feed the higher inflation we started with. Consequently, non-fundamentally induced changes in expectations cannot cause aggregate demand and inflation to jump on impact as predicted by the C model. Now consider the case where the central bank raises the nominal interest rate by more than one for one to changes in inflation in the B model, but does not react on broad money ($\rho_\pi > 1$, $\rho_a = 0$). A rise in inflation is then associated with a higher real interest rate leading to a positive growth rate of output (see, 30). The real wealth condition (32) demands, again for a_t predetermined, that output rises above its steady state value as the sum of the remaining two variables on the right hand side of (32) clearly decreases for an active rule. Given the positive output growth and that the upward jump in output enforces the rise in inflation, the economy evolves on a explosive path.

Why can the central bank restore macroeconomic stability in the B model with an active policy if it reacts sufficiently to changes in real broad money? In order to answer this question, we have to take the first order condition for broad money in subsequent periods into consideration. It predicts that households will adjust their broad money holdings downwards, as long as they expect a rise in future interest rates exceeding a potential rise in output and inflation. Evidently, the latter would be the case for an active interest rate policy. Hence, if the central bank reacts to the decline in real broad money by lowering the nominal interest rate, it induces a decline in the real interest rate and, therefore, in consumption growth in the subsequent periods, thereby, ruling out explosive behavior.

4 Optimal monetary policy

In this section, we examine the role of real broad money for optimal interest rate policy. Applying numerical methods we solve for the optimal allocations in the B and the C model. As expected, the fundamental solutions (reaction functions) for the monetary policy instrument differ with regard to the appearance of real broad money. We further find that the optimal allocation is uniquely determined in the B model and indeterminate in the C model. In order to assess the importance of broad money for optimal monetary policy, we compute realized losses for different instrument reaction functions in the B model.[16] The results indicate that the negligence of a predetermined

[16] Similar comparisons between different policies on basis of numerically derived losses for variants of the C model are provided by McCallum and Nelson (2000) and Woodford (1999b).

variable, here, real broad money, can have substantial effects on the performance of interest rate policy.

Flexible inflation targeting Given that an optimal monetary policy should maximize welfare, the central bank's objective should be based on the households lifetime utility given in (1). However, in order to facilitate comparisons with related work, we assume that the central bank's objective is to stabilize the economy. We assume that the central bank aims at minimizing an intertemporal loss function representing the objective of a central bank which is engaged in a flexible interest rate targeting as defined in Svensson (1997). More specifically, in period $t0$, the loss function is given by

$$L_{t0} = -\frac{1}{2} E_{t0} \left(\sum_{t=t0}^{\infty} \beta^{t-t0} \left(\hat{\pi}_t^2 + \alpha \widehat{y}_t^2 \right) \right). \tag{36}$$

This loss function can be interpreted as a second-order Taylor approximation to the expected utility of the representative consumer.[17] For this approximation to be valid, it is implicitly assumed that the distortions due to monopolistic competition in the goods market and due to the steady state distortion of monopolistic wage setting are eliminated by the fiscal authority through an appropriate system of lump-sum transfers. Moreover, we assume the steady state gross inflation to be one. It should further be noted that output deviations instead of output gap deviations enter the loss function for convenience. While in general these measures are not identical whenever the potential output level departs from the actual output, they only differ by unequal steady state values in our environment.

The central bank chooses a sequence of interest rates and a sequence of private sector allocations in order to maximize (36), taking the sequence of private sector equilibrium conditions (30), (31), and (32) as constraints. The central bank does not re-optimize each period, or in other words, we derive the optimal interest rate policy under commitment (see, Clarida et al., 1999, or, Woodford, 1999a).[18] The following proposition summarizes the outcome of the policy problem.

[17] For a formal derivation, see Woodford (2002c).

[18] Since the seminal work of Kydland and Prescott (1977) it is well known that monetary policy might face a time-consistency problem. Here, we do not investigate the issue of implementation.

Proposition 4 *The optimal policy under commitment*

1. *in the B model is characterized by a set of sequences for the endogenous variables (π, y, a, R) satisfying the equilibrium conditions (30), (31), (32), and the following targeting and initial rules:*

$$\widehat{y}_t - \widehat{y}_{t-1} = -\frac{\gamma}{\alpha}\widehat{\pi}_t \quad \forall t > t_0, \tag{37}$$

$$\widehat{y}_{t0} = -\frac{\gamma}{\alpha}\widehat{\pi}_{t0}, \tag{38}$$

2. *in the C model is characterized by a set of sequences for the endogenous variables (π, y, R) satisfying the equilibrium conditions (30), (31), and the targeting rule (37) and the initial rule (38).*

Proof. See appendix 6.7. ■

Remarkably, the so-called targeting rule (37), which repeatedly appears in the literature on inflation targeting (see, e.g., Clarida et al., 1999, or Svensson, 2001), is identical in both versions of our model. As shown in the proof, this is due to the fact that the aggregate supply constraint (31) is the single binding condition for the optimality problem such that the shadow prices on all equilibrium conditions and, particularly, on the first order condition for broad money (32) are equal to zero. Nevertheless, the implied fundamental solution (reaction function) for the nominal interest rate differs between the B and the C model because real broad money enters the solution only in the B model. The optimality condition (37) indicates a path dependence of optimal monetary policy such that past values of output are also treated as predetermined state variables (see, Woodford, 1999a). The initial rule (38), in fact, differs from the general targeting rule (37) because values of output prior to period $t0$ do not influence output and inflation between $t0$ and infinity. However, in the sequel we will ignore the fact that the first-order conditions differ at the point in time when the central bank implements its optimal plan. This is closely related to adopting the so called timeless perspective of optimal policy investigated by Woodford (1999a,b) and McCallum and Nelson (2000).[19] While the fundamental solution for the nominal interest rates can

[19] The term timeless perspective stands for the assumption that the central bank behaves as if it implemented its optimal policy plan infinitely many periods ago. For details of this concept see, especially, Woodford (1999b).

easily be derived in the case of the C model (see, appendix 6.8 or Clarida et al., 1999), we rely on numeric methods to examine optimal interest rate policies for the B model.

Table 1 Values for structural parameters

Parameter	σ, σ_c, σ_l	ϵ	β	$\bar{l}$	$1-\phi$	$\overline{\pi}$	σ_μ	ρ_μ	α
Values	2	6	0.99	0.5	0.8	1.0	0.005	0.9 (0)	0.3 (0.5)

A quantitative analysis In order to solve numerically for the optimal allocation and the corresponding interest rates, the B model is calibrated at the steady state by taking parameter values corresponding to related literature and roughly matching their empirical counterparts (see table 1). The length of a time period is one-quarter. We solve for the optimal allocation in the B model and the C model using Blanchard and Kahn's (1983) solution method. The B model contains the three conditions (30)-(32) as well as the targeting rule (37) such that the nominal interest rate is now an endogenous variable. In case of our B model, the state space is spanned by the exogenous state $\widehat{\mu}_t$, the stock of real broad money $\widehat{a}_t$, and the previous value of output $\widehat{y}_{t-1}$. In contrast, the C model does not include real broad money, so that the state space just consists of $\widehat{\mu}_t$ and $\widehat{y}_{t-1}$. In accordance with our analytical results of the previous section, we find that the optimal allocation is associated with a unique equilibrium in the B model, whereas we obtain multiple rational expectations equilibrium paths for optimal policy in the C model; the latter finding is also reported in Svensson and Woodford (1999).[20]

Finally, we calculate the realized losses in the B model using different interest rate reaction functions. The first reaction function, which is called $B1$ policy, is the fundamental solution for the interest rate in the optimal allocation derived above. The second reaction function is the optimal interest rate of the C model, called C policy. This experiment can be interpreted as a sensible rule for a central bank that erroneously ignores the influence of broad money on the economy. Note that such a central bank might not detect that it is using the wrong model because the B model

[20] For further restriction on optimal policy rules to ensure determinacy see Giannoni and Woodford (2002).

nests the C version as shown in the previous section. As a third policy, labelled $B2$, we apply an interest rate reaction function derived in the B model for the case where the targeting rule in (37) is replaced by the static condition: $\alpha\widehat{y}_t = -\gamma\widehat{\pi}_t$.[21]

Table 2 Losses in the B model for different interest rate reaction functions

Values for		Interest rate policy			Values for		Interest rate policy		
$\rho_\mu = 0.9$	α	$B1$	$B2$	C	$\rho_\mu = 0$	α	$B1$	$B2$	C
	0.3	0.13	0.66	10.8		0.3	0.0038	0.006	0.32
	0.5	0.21	0.71	5.18		0.5	0.0043	0.0065	0.11

Notes: reported value are means of realized losses times 10^4

The means of realized losses presented in table 1 are estimated using 1000 identical realizations for the innovations to the cost push shock process (10). The realized losses for the C policy are always much higher for persistent ($\rho_\mu = 0.9$) than for transitory shocks ($\rho_\mu = 0$). The differences in the performance of the B1 and the B2 policy are quite modest and broadly comparable with the findings in McCallum and Nelson (2000). The presence of the additional state variable, a_t, is responsible for interest rate responses to cost push shocks being always much less pronounced for the $B1$ and $B2$ policy than for the C policy. The inferior performance of the C policy, which is worsened for a smaller weight on output gap, $\alpha = 0.3$, indicates that strong interest rate responses increase output and, especially, inflation fluctuations caused by the wealth effect of broad money adjustments. This demonstrates that applying the targeting rule (37) in the 'wrong' (C) model is worse than applying the inferior targeting rule ($\alpha\widehat{y}_t = -\gamma\widehat{\pi}_t$) in the 'right' ($B$) model.

5 Conclusion

In this paper it was shown that real broad money can have a substantial effect on macroeconomic stability. When households' wealth consists of inside and outside

[21] This condition is can be found in the literature for the case that the central bank does not commit itself to a once and for all policy, but is allowed to re-optimize in every period (see, e.g., Clarida et al. 1999). It can easily be shown that this rule corresponds to the optimal interests policy under discretion also in our model B.

money, real broad money equals total financial wealth, which is a predetermined variable. As both components of broad money, i.e., cash and deposits, provide transaction services, real wealth affects aggregate demand. A stable equilibrium can always uniquely be determined as long as the central bank reacts, at least slightly, on the real broad money gap. Therefore, this model is less vulnerable to undesirable dynamics due to multiple or unstable equilibria than more conventional monetary business cycle models. Moreover, real broad money is found to enter an optimal interest rate reaction function of a central bank which aims at minimizing a standard loss function. It is further demonstrated that the negligence of real broad money due to model misperception leads to considerably higher losses. Remarkably, the arguments for real broad money to be non-negligible are independent of the strength of the wealth effect as they build on the property of real broad money as an endogenous state variable.

The model developed in this paper, clearly, exhibits several simplifying assumption, such as a separable utility function, the negligence of capital accumulation, or households having no direct access to bonds. Nevertheless, the underlying real wealth effect does not depend on these assumptions and operates as long as all financial assets held by households raise aggregate demand via the reduction of transaction services. In this case, a central bank should react to changes in a broadly defined real monetary aggregate serving as a proxy for real financial wealth.

6 Appendix

6.1 Derivation of the New Keynesian Phillips Curve

In each period a measure $1-\phi$ of randomly selected retailer set new prices $\widetilde{P}_{it}$ in order to maximize the value of their shares for a given price level for the previous period P_{-1} :

$$\max_{\widetilde{P}_{it}} E_t \left[\sum_{s=0}^{\infty} (\beta\phi)^s \vartheta_{t,t+s} \left(\overline{\pi}^s \widetilde{P}_{it} y_{it+s} - P_{t+s} mc_{t+s} y_{it+s}) \right) \right],$$
$$\text{subject to } y_{it+s} = \left(\overline{\pi}^s \widetilde{P}_{it} \right)^{-\epsilon} P_{t+s}^{\epsilon} y_{t+s},$$

where mc is the inverse of the retailer's mark-up μ_P. Since the retail firms are owned by the households, the weights $\vartheta_{t,t+s}$ of dividend payments depends on the marginal utilities of consumption: $\vartheta_{t,t+s} = \frac{\lambda_{t+s}}{\lambda_t} \frac{P_t}{P_{t+s}}$. The first order condition for the optimal price setting of re-optimizing producers is given by

$$\widetilde{P}_{it} = \frac{\epsilon}{\epsilon - 1} \frac{\sum_{s=0}^{\infty} (\beta\phi)^s E_t \left[\vartheta_{t,t+s} y_{t+s} P_{t+s}^{\epsilon+1} \overline{\pi}^{-\epsilon s} mc_{t+s} \right]}{\sum_{s=0}^{\infty} (\beta\phi)^s E_t \left[\vartheta_{t,t+s} y_{t+s} P_{t+s}^{\epsilon} \overline{\pi}^{(1-\epsilon)s} \right]}. \tag{39}$$

Using a simple price rule for the fraction ϕ of the retailer ($P_{it} = \overline{\pi} P_{it-1}$), the price index for the final good P_t evolves recursively over time. In a symmetric equilibrium we obtain the following condition for the evolution of the price level: $P_t^{1-\epsilon} = \phi \left(\overline{\pi} P_{t-1} \right)^{1-\epsilon} + (1-\phi) \widetilde{P}_t^{1-\epsilon}$, which can be written in stationary variables as:

$$1 = \left[\phi \left(\overline{\pi} \pi_t^{-1} \right)^{1-\epsilon} + (1-\phi) \widetilde{P}_{qt}^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}, \text{with } \widetilde{P}_{qt} = \frac{\widetilde{P}_{it}}{P_t} \text{ and } \pi_t = \frac{P_t}{P_{t-1}}, \tag{40}$$

where $\widehat{x}$ denotes the percent deviation of x from its steady state value $\overline{x}$. Linearization of (40) at the steady state leads to:

$$\frac{\phi}{1-\phi} \widehat{\pi}_t = \widehat{\widetilde{P}}_{qt}. \tag{41}$$

Further, we transform the first order condition for the retailer's optimal price $\widetilde{P}_{it}$ (39) in stationary variables:

$$\widetilde{P}_{qt} \frac{\epsilon - 1}{\epsilon} \sum_{s=0}^{\infty} (\beta\phi)^s E_t \left[\vartheta_{t,t+s} y_{t+s} \pi_{t,t+s}^{\epsilon} \overline{\pi}^{(1-\epsilon)s} \right] = \sum_{s=0}^{\infty} (\beta\phi)^s E_t \left[\vartheta_{t,t+s} y_{t+s} \pi_{t,t+s}^{\epsilon+1} mc_{t+s} \overline{\pi}^{-\epsilon s} \right], \tag{42}$$

where $\pi_{t,t+s}$ denotes a cumulative inflation rate: $\pi_{t,t+s} = \frac{P_{t+s}}{P_t} = \prod_{k=1}^{s} \pi_{t+k}$. Linearizing equation (42) at the steady state we obtain:

$$\sum_{s=0}^{\infty} (\beta\phi)^s \overline{\widetilde{P}}_q \frac{\epsilon-1}{\epsilon} \overline{y\pi}^{(1-\epsilon)s} \overline{\pi}^{s(\epsilon-1)} E_t \left[\widehat{\vartheta}_{t,t+s} + \widehat{y}_{t+s} + \epsilon \widehat{\pi}_{t,t+s} + \widehat{\overline{\widetilde{P}}}_{qt} \right] \tag{43}$$
$$= \sum_{s=0}^{\infty} (\beta\phi)^s \overline{mcy\pi}^{-\epsilon s} \overline{\pi}^{s\epsilon} E_t \left[\widehat{\vartheta}_{t,t+s} + \widehat{y}_{t+s} + (\epsilon+1) \widehat{\pi}_{t,t+s} + \widehat{mc}_{t+s} \right].$$

Using $\overline{\widetilde{P}}_q \frac{\epsilon-1}{\epsilon} = \overline{mc}$ and substituting $\overline{\widetilde{P}}_q$ out with (41), equation (43) can be simplified to:

$$\frac{\phi}{(1-\phi)} \widehat{\pi}_t = (1-\beta\phi) \sum_{s=0}^{\infty} (\beta\phi)^s E_t \left[\widehat{\pi}_{t,t+s} + \widehat{mc}_{t+s} \right]. \tag{44}$$

Taking the period $t+1$ version of (44) times $\beta\phi$ and substracting from (44), gives:

$$\frac{\phi}{(1-\phi)} \left(\widehat{\pi}_t - \beta\phi E_t \left[\widehat{\pi}_{t+1} \right] \right) = (1-\beta\phi) \left(\widehat{mc}_t - \beta\phi \sum_{s=0}^{\infty} (\beta\phi)^s E_t \left[-\widehat{\pi}_{t+1} \right] \right). \tag{45}$$

Rewriting equation (45) leads to the 'New Keynesian Phillips Curve' (28):

$$\widehat{\pi}_t = \chi \widehat{mc}_t + \beta E_t \left[\widehat{\pi}_{t+1} \right], \text{ with } \chi = (1-\phi)(1-\beta\phi)\phi^{-1}.$$

6.2 Proof of proposition 1

The claims made in the proposition can easily be derived from stationary equilibrium conditions. Combining the first order condition for labor supply (9) with the resource constraint, $\overline{mc}/\mu = u_l(1-\overline{c})/u_c(\overline{c})$, uniquely determines the stationary value of consumption and output. The production function and the labor supply condition (9) then uniquely determine labor and output. The stationary inflation rate is determined by the interest rate policy given in definition 1 and the first order condition for bonds (17) at the steady state, $\overline{\pi} = \bar{R}\beta$. Combining the steady state expressions of the household's first order conditions steady state (3), (4), and (5) with FOC on bonds for the banks (17) gives $u_m(\overline{m}^h) = u_c(\overline{c})(R-1)$. The FOC's of the bank then yield: $\overline{i}^d = (1-\theta)(R-1)$, and $\overline{i}^c = (R-1)$. Combining (3), (4), (5) and (17) yields $u_d(\overline{d}) = u_m(\overline{m}^h)\theta$, what in the B version determines $\overline{d}$ and, therefore, also $\overline{a} = \overline{\pi}\left(\overline{m}^h + \overline{d}\right)$ and $\overline{m}^b = \theta\overline{d}$. It can be immediately seen that in the B model $\partial\overline{d}/\partial\theta$, $\partial\overline{a}/\partial\theta$, and $\partial\overline{i}^d/\partial\theta$ are strictly negative, and that $\partial m^b/\partial\theta = \overline{d} + \overline{u}_m\theta/\overline{u}_{dd}$ is strictly positive if $-\overline{u}_{dd}\overline{d}/\overline{u}_d > 1$. This completes the proof. ■

6.3 Reduction of the model

In this appendix, we derive the linearized reduced form model used in section 3 and 4. To save on notation, values without subscript denote steady state values in this appendix. Combining household's FOC on deposits (5) with the bank's FOC on bonds yields

$$E_t\left[\frac{\partial u}{\partial d_{t+1}}\frac{1}{\pi_{t+1}}\right] = E_t\left[\frac{R_{t+1}}{\pi_{t+1}}\lambda_{t+1}\right] - E_t\left[\lambda_{t+1}\frac{R^d_{t+1}}{\pi_{t+1}}\right].$$

Linearizing and using the steady state conditions $\lambda = u_c$ and $u_d = u_c\left(R - R^d\right)$ yields

$$\overline{u}_{dd}\overline{d}E_t\widehat{d}_{t+1} = u_c E_t\left(R\widehat{R}_{t+1} - R^d\widehat{R}^d_{t+1}\right) + u_c\left(R - R^d\right)E_t\widehat{\lambda}_{t+1}.$$

Applying certainty equivalence leads to

$$u_{dd}d\widehat{d}_t = u_c\left(R\widehat{R}_t - R^d\widehat{R}^d_t\right) + u_c\left(R - R^d\right)\widehat{\lambda}_t. \tag{46}$$

Linearizing (3) gives

$$-\sigma_c\widehat{c}_t = \widehat{\lambda}_t. \tag{47}$$

Linearizing (4), using the steady state condition $\lambda = u_c$ and inserting (47) leads to

$$-\sigma u_m\widehat{m}^h_t = u_{dd}d\widehat{d}_t + u_c R^d\widehat{R}^d_t - u_c(R^d - 1)\sigma_c\widehat{c}_t. \tag{48}$$

Inserting (46) into (48) gives

$$\widehat{m}^h_t = -\frac{u_c R}{u_m\sigma}\widehat{R}_t + \frac{u_c(R-1)\sigma_c}{u_m\sigma}\widehat{c}_t.$$

and using the steady state condition $u_m = u_c\left(R - 1\right)$, see proof of proposition 1, we obtain a money demand function

$$\widehat{m}^h_t = -\frac{R}{\left(R-1\right)\sigma}\widehat{R}_t + \frac{\sigma_c}{\sigma}\widehat{c}_t.$$

The term money demand function is used in a slightly abused form, as we also used a FOC of the financial intermediaries to obtain this equilibrium condition. Similarly, inserting (47), $u_{dd}d\widehat{d}_t = -\sigma u_d\widehat{d}_t$ and the steady state condition on deposits, written as

$u_d = u_c\left(R - R^d\right)$, into (46) leads to a deposit demand function

$$\widehat{d}_t = -\frac{1}{\sigma}\frac{R\widehat{R}_t - R^d\widehat{R}_t^d}{R - R^d} + \frac{\sigma_c}{\sigma}\widehat{c}_t.$$

Linearizing the definition of broad money gives

$$\widehat{a}_t - \widehat{\pi}_t = \frac{m^h}{a/\pi}\widehat{m}_t^h + \frac{d}{a/\pi}\widehat{d}_t.$$

Inserting demand for cash and deposits leads to

$$\widehat{a}_t - \widehat{\pi}_t = \left(\frac{d}{a/\pi} + \frac{m^h}{a/\pi}\right)\frac{\sigma_c}{\sigma}\widehat{c}_t - \frac{d}{a/\pi}\frac{R\widehat{R}_t - R^d\widehat{R}_t^d}{\sigma\left(R - R^d\right)} - \frac{m^h}{a/\pi}\frac{R}{(R-1)\,\sigma}\widehat{R}_t.$$

Linearizing $R_t^d = \theta + (1-\theta)\,R_t$ and $R^d\widehat{R}_t^d = (1-\theta)\,R\widehat{R}_t$ and using the market clearing condition $y_t = c_t$ yields the equilibrium condition for real broad money (32)

$$\widehat{a}_t = \widehat{\pi}_t + \frac{\sigma_c}{\sigma}\widehat{y}_t - \frac{R}{(R-1)}\frac{1}{\sigma}\widehat{R}_t.$$

real marginal costs are given by

$$mc_t = \frac{u_{lt}}{u_{ct}}\mu_t.$$

Linearizing the labor supply condition (9) and using market clearing and the production function gives

$$\widehat{mc}_t = \left(\sigma_l\frac{\bar{l}}{1-\bar{l}} + \sigma_c\right)\widehat{y}_t + \widehat{\mu}_t = \omega_1\widehat{y}_t + \widehat{\mu}_t.$$

Inserting into the linearized price equation (28), we obtain the forward looking Phillips curve.

$$\widehat{\pi}_t = \chi\omega_1\widehat{y}_t + \beta E_t[\widehat{\pi}_{t+1}] + \chi\widehat{\mu}_t. \tag{49}$$

Finally, combining the first order condition on bank demand for deposits with the first-order condition on consumptions and using market clearing and leads, after linearizing, to the standard IS curve.

$$\widehat{y}_t = E_t\widehat{y}_{t+1} - \frac{1}{\sigma_c}E_t\left[\widehat{R}_{t+1} - \widehat{\pi}_{t+1}\right] \tag{50}$$

6.4 Proof of Proposition 2

By inserting the lead of the interest rate rule, we can write IS and AS curve in Matrix notation as

$$\begin{pmatrix} \widehat{y}_t \\ \widehat{\pi}_t \end{pmatrix} = \begin{pmatrix} 1 & \frac{1-\rho_\pi}{\sigma_c} \\ \gamma & \frac{\gamma(1-\rho_\pi)+\sigma_c\beta}{\sigma_c} \end{pmatrix} \begin{pmatrix} \widehat{y}_{t+1} \\ \widehat{\pi}_{t+1} \end{pmatrix}.$$

This forward-looking system is determinate if both eigenvalues lie inside the unit circle. The characteristic polynomial for these eigenvalues is

$$f(X) = X^2 - \left(1 + \beta + \frac{\gamma}{\sigma_c}(1-\rho_\pi)\right) X + \beta,$$

with

$$f(0) = \beta > 0, \quad f(1) = -\frac{\gamma}{\sigma_c}(1-\rho_\pi).$$

Hence, for passive rules ($\rho_\pi < 1$) we will have one eigenvalue between zero and one and one eigenvalue larger than one, implying indeterminacy. As $\frac{\partial f(X)}{\partial X} = 2X - 1 - \beta + \frac{\gamma}{\sigma_c}(\rho_\pi - 1)$ is positive for active rules ($\rho_\pi > 1$) if $X \geq 1$, there is no eigenvalue larger than 1 for active rules. To rule out indeterminacy for active rules, we first investigate whether $f(-1) > 0$

$$\begin{aligned} f(-1) &= 2 + 2\beta - \frac{\gamma}{\sigma_c}(\rho_\pi - 1) > 0 \\ &\Rightarrow \rho_\pi < 1 + \frac{\sigma_c}{\gamma} 2(1+\beta) \end{aligned}$$

Hence, we have one eigenvalue smaller than -1 and one between -1 and 0 if $\rho_\pi > 1 + \frac{\sigma_c}{\gamma} 2(1+\beta)$, implying indeterminacy. Finally, to rule out two eigenvalues smaller than -1 (explosive behavior), we investigate whether $\frac{\partial f(X)}{\partial X}$ is negative at -1 when $f(-1) > 0$

$$\begin{aligned} \left.\frac{\partial f(X)}{\partial X}\right|_{X=-1} &= -3 - \beta - \frac{\gamma}{\sigma_c}(1-\rho_\pi) < 0 \\ &\Rightarrow \rho_\pi < 1 + \frac{\sigma_c}{\gamma}(3+\beta) \end{aligned}$$

As $(3+\beta) > 2(1+\beta)$, we can rule out explosive equilibria. Hence, we have a unique rational equilibrium path converging to the steady state if and only if

$$1 < \rho_\pi < 1 + 2(1+\beta)\frac{\sigma_c}{\gamma}$$

This completes the proof. ■

6.5 Proof of Proposition 3

First, we reduce the system in inflation, output and real wealth into a two dimensional system in inflation and real wealth only. For that, write the real wealth equation of the three dimensional system as

$$\widehat{y}_t = \frac{1}{\sigma_c}\frac{\overline{R}}{\overline{R}-1}\widehat{R}_t - \frac{\sigma}{\sigma_c}\widehat{\pi}_t + \frac{\sigma}{\sigma_c}\widehat{a}_t.$$

Moreover, the FOC for real wealth in the next period, $\widehat{a}_{t+1}$, can similarly be solved for expected future output as

$$E_t\widehat{y}_{t+1} = \frac{1}{\sigma_c}\frac{\overline{R}}{\overline{R}-1}E_t\widehat{R}_{t+1} - \frac{\sigma}{\sigma_c}E_t\widehat{\pi}_{t+1} + \frac{\sigma}{\sigma_c}\widehat{a}_{t+1}.$$

Inserting these two expressions into the IS (or consumption Euler) equation, we end up in a 2×2 system in a, π and the policy instrument R

$$\begin{aligned}
\sigma\widehat{a}_{t+1} + (1-\sigma)E_t\widehat{\pi}_{t+1} &= \sigma\widehat{a}_t - \sigma\widehat{\pi}_t + \frac{\overline{R}}{\overline{R}-1}\widehat{R}_t - \frac{1}{\overline{R}-1}E_t\widehat{R}_{t+1} \\
-\sigma_c\beta E_t\widehat{\pi}_{t+1} &= \chi\omega_1\sigma\widehat{a}_t - (\chi\omega_1\sigma + \sigma_c)\widehat{\pi}_t + \chi\omega_1\frac{\overline{R}}{\overline{R}-1}\widehat{R}_t + \sigma_c\chi\widehat{\mu}_t
\end{aligned}$$

We investigate interest rate rules represented by

$$\widehat{R}_t = \rho_a\widehat{a}_t + \rho_\pi\widehat{\pi}_t$$

For the local stability analysis we have to investigate only the non-stochastic part of the dynamic system. Therefore, our results also hold for any interest rate rule that depends on current or past values of the exogenous shock processes. The deterministic part of our two dimensional system is

$$\begin{pmatrix} \sigma + \frac{\rho_a}{R-1} & 1 - \sigma + \frac{\rho_\pi}{R-1} \\ 0 & -\sigma_c \beta \end{pmatrix} \begin{pmatrix} \widehat{a}_{t+1} \\ \widehat{\pi}_{t+1} \end{pmatrix} = \begin{pmatrix} \sigma + \frac{\rho_a R}{R-1} & -\sigma + \frac{\rho_\pi R}{R-1} \\ \gamma \left(\sigma + \frac{\rho_a R}{R-1} \right) & -\gamma \left(\sigma - \frac{\rho_\pi R}{R-1} \right) - \sigma_c \end{pmatrix} \begin{pmatrix} \widehat{a}_t \\ \widehat{\pi}_t \end{pmatrix}$$

where $\gamma = \chi \omega_1$. We investigate the eigenvalues of

$$M = \begin{pmatrix} \sigma + \frac{\rho_a}{R-1} & 1 - \sigma + \frac{\rho_\pi}{R-1} \\ 0 & -\sigma_c \beta \end{pmatrix}^{-1} \begin{pmatrix} \sigma + \frac{\rho_a R}{R-1} & -\sigma + \frac{\rho_\pi R}{R-1} \\ \gamma \left(\sigma + \frac{\rho_a R}{R-1} \right) & -\gamma \left(\sigma - \frac{\rho_\pi R}{R-1} \right) - \sigma_c \end{pmatrix}$$

Since we have one forward-looking and one backward-looking variable, the system is determinate if one eigenvalue of M is larger than one in absolute value, while the other is smaller. The characteristic equation of M is given by

$$\begin{aligned} f(X) = {} & X^2 - \frac{1}{\beta} \frac{\sigma (R-1) \left(1 + \beta + \frac{\gamma}{\sigma_c} \right) + \rho_a \left(1 + \left(\beta + \frac{\gamma}{\sigma_c} \right) R \right) - (\rho_a + \rho_\pi) \frac{\gamma}{\sigma_c} \sigma (R-1)}{\sigma (R-1) + \rho_a} X \\ & + \frac{1}{\beta} \frac{\sigma (R-1) + \rho_a R}{\sigma (R-1) + \rho_a} \end{aligned}$$

Since f is concave and $f(0) > 0$ if ρ_a is positive, we have one eigenvalue between zero and one and one eigenvalue larger than one if $f(1) < 0$. This condition is

$$\begin{aligned} & \sigma (R-1)(1+\beta) + \rho_a (\beta + R) \\ & < \sigma (R-1) \left(1 + \beta + \frac{\gamma}{\sigma_c} \right) + \rho_a \left(1 + \left(\beta + \frac{\gamma}{\sigma_c} \right) R \right) - (\rho_a + \rho_\pi) \frac{\gamma}{\sigma_c} \sigma (R-1) \\ & \Rightarrow \rho_\pi < 1 + \rho_a \left(\frac{1 - (R-1)(\sigma - 1)}{\sigma (R-1)} - \frac{1-\beta}{\sigma \frac{\gamma}{\sigma_c}} \right) \end{aligned}$$

This proves the first part of the condition in proposition 1.

Note that if $f(-1) < 0$, we have one eigenvalue smaller than -1 and one eigenvalue between -1 and 0. This condition, that also ensures determinacy, can be written as

$$\begin{aligned} & \sigma (R-1)(1+\beta) + \rho_a (\beta + R) \\ & < -\sigma (R-1) \left(1 + \beta + \frac{\gamma}{\sigma_c} \right) - \rho_a \left(1 + \left(\beta + \frac{\gamma}{\sigma_c} \right) R \right) + (\rho_a + \rho_\pi) \frac{\gamma}{\sigma_c} \sigma (R-1) \\ & \Rightarrow \rho_\pi > 1 + 2(1+\beta) \frac{\sigma_c}{\gamma} + \rho_a \left(\frac{R + (1+\beta)(1+R)}{\frac{\gamma}{\sigma_c} \sigma (R-1)} + \frac{1 - (R-1)(\sigma - 1)}{\sigma (R-1)} \right) \end{aligned}$$

This completes the proof. ■

6.6 Proof of Corollary 1

It follows directly from proposition 2 that an active interest rate rule together with a positive feedback on broad money can ensure determinacy only if

$$\left(\frac{1}{(R-1)}+(\sigma-1)-\sigma_c\frac{1-\beta}{\chi\omega_1}\right)>0. \tag{51}$$

Using the expression for the slope of the Phillips curve ($\chi\omega_1$) and the steady state condition of the real interest rate, this condition can be written as

$$\frac{\beta}{\bar{\pi}-\beta}+(\sigma-1)>\frac{1-\beta}{1+\frac{\sigma_n}{\sigma_c}\frac{\bar{l}}{1-\bar{l}}}\frac{\phi}{(1-\phi)(1-\beta\phi)}$$

Since

$$\frac{\beta}{\bar{\pi}-\beta}<(\sigma-1)+\frac{\beta}{\bar{\pi}-\beta}\beta,\quad \text{and } \frac{\phi}{1-\phi}>\frac{1}{1+\frac{\sigma_n}{\sigma_c}\frac{\bar{l}}{1-\bar{l}}}\frac{1-\beta}{1-\beta\phi}\frac{\phi}{1-\phi}$$

$\frac{\beta}{\bar{\pi}-\beta}>\frac{\phi}{1-\phi}$ is a sufficient condition for (51). ■

6.7 Proof of Proposition 4

The central bank sets the interest rate $\widehat{R}_t$ in period t, so that the nominal return on a government bond bought in t and paid back in $t+1$ is not known in t. Formally, the maximization problem of the Central Bank can be expressed by the following Lagrangian:

$$-E_{t0}\sum_{t=t0}^{\infty}\beta^{t-t0}\begin{pmatrix}\frac{1}{2}\hat{\pi}_t^2+\frac{1}{2}\alpha\widehat{y}_t^2\\ +\phi_{1t}\left[\widehat{y}_t-\widehat{y}_{t+1}-\frac{1}{\sigma_c}\hat{\pi}_{t+1}+\frac{1}{\sigma_c}\widehat{R}_{t+1}\right]\\ +\phi_{2t}\left[\widehat{\pi}_t-\chi\omega_1\widehat{y}_t-\beta\widehat{\pi}_{t+1}-\chi\widehat{\mu}_t\right]\\ +\phi_{3t}\left[-\sigma\widehat{a}_t+\sigma\widehat{\pi}_t-\frac{\bar{R}}{\bar{R}-1}\widehat{R}_t+\sigma^c\widehat{y}_t\right]\end{pmatrix}.$$

The FOC with respect to $\widehat{\pi}_t$, $\widehat{y}_t$, $\widehat{a}_{t+1}$, and $\widehat{R}_t$ are

$$-\widehat{\pi}_t+\phi_{1t-1}\sigma_c^{-1}-\phi_{2t}+\phi_{2t-1}-\sigma\phi_{3t}=0, \tag{52}$$

$$-\alpha\widehat{x}_t-\phi_{1t}+\beta^{-1}\phi_{1t-1}+\phi_{2t}\chi\omega_1-\sigma^c\phi_{3t}=0, \tag{53}$$

$$\beta\phi_{3t+1}\sigma=0, \tag{54}$$

$$-\frac{1}{\beta}\phi_{1t-1}\frac{1}{\sigma_c}+\phi_{3t}\frac{\bar{R}}{\bar{R}-1}=0. \tag{55}$$

It can immediately be seen that (54) and (55) imply $\phi_{3t} = 0 \quad \forall t > t0$ and hence $\phi_{1t} = 0 \quad \forall t$. Moreover, as $\phi_{1t0-1} = 0$ by construction, (55) also implies that $\phi_{3t0} = 0$. We can rewrite the FOC on output and inflation as

$$-\widehat{\pi}_t - \phi_{2t} + \phi_{2t-1} = 0,$$

$$-\alpha\widehat{y}_t + \phi_{2t}\chi\omega_1 = 0.$$

Finally, eliminating the Lagrange multiplier, using that $\phi_{2t0-1} = 0$ and defining $\gamma = \chi\omega_1$ yields the targeting rule

$$\widehat{y}_t - \widehat{y}_{t-1} = -\frac{\gamma}{\alpha}\widehat{\pi}_t \quad \forall t > t0$$

$$\widehat{y}_{t0} = -\frac{\gamma}{\alpha}\widehat{\pi}_{t0}$$

This completes the proof. ■

6.8 Optimal interest rates in the C model

With the functional form for the targeting rule one can easily derive an analytical solution for an interest rate rule in the C model (see, Clarida et al. 1999). First, combine (37) with the AS curve to eliminate current inflation

$$\left(1+\frac{\gamma^2}{\alpha}\right)\widehat{y}_t = \widehat{y}_{t-1} - \beta\frac{\gamma}{\alpha}E_{t+i}\widehat{\pi}_{t+1} - \frac{\gamma}{\alpha}\chi\widehat{\mu}_t, \quad \text{with} \quad \gamma = \chi\omega_1. \tag{56}$$

Next, iterate (37) one period ahead and take expectations to get

$$E_t\widehat{\pi}_{t+1} = \frac{\alpha}{\gamma}\widehat{y}_t - \frac{\alpha}{\gamma}E_t\widehat{y}_{t+1}.$$

Inserting this into (56) gives

$$\widehat{y}_t = \frac{\alpha}{\alpha(1+\beta)+\gamma^2}\left(\widehat{y}_{t-1} + \beta E_t\widehat{y}_{t+1} - \frac{\gamma}{\alpha}\chi\widehat{\mu}_t\right).$$

The solution to this second order stochastic difference equation is given by

$$\widehat{y}_t = \delta \widehat{y}_{t-1} - \frac{\delta\gamma\chi}{\alpha\left(1-\delta\beta\rho_\mu\right)}\widehat{\mu}_t, \quad \text{with} \quad \delta = \frac{1-\sqrt{1-4\beta z^2}}{2\beta z}, \quad z = \frac{\alpha}{\alpha\left(1+\beta\right)+\gamma^2}, \tag{57}$$

which is stable as $0 < \delta < 1$ holds. Iterating (57) one period ahead and taking expectations gives

$$E_t \widehat{y}_{t+1} = \delta^2 \widehat{y}_{t-1} - \frac{\gamma\chi\delta\left(\delta+\rho_\mu\right)}{\alpha\left(1-\delta\beta\rho_\mu\right)}\widehat{\mu}_t.$$

By inserting (57) into (37) we can determine the optimal value for current inflation as

$$\widehat{\pi}_t = \frac{\alpha\left(1-\delta\right)}{\gamma}\widehat{y}_{t-1} + \frac{\delta\chi}{\left(1-\delta\beta\rho_\mu\right)}\widehat{\mu}_t.$$

From this expression we also obtain

$$E_t \widehat{y}_{t+1} = \frac{\alpha\delta\left(1-\delta\right)}{\gamma}\widehat{y}_{t-1} + \frac{\delta\chi\left(\rho_\mu+\delta-1\right)}{\left(1-\delta\beta\rho_\mu\right)}\widehat{\mu}_t. \tag{59}$$

The fundamentals based optimal interest rate rule under commitment can then be derived from inserting (57) to (59) into the IS curve and solving for $\widehat{R}_t$:

$$\widehat{R}_t = \left(1-\delta\right)\left(\frac{\alpha}{\gamma}-\sigma_c\right)\widehat{y}_{t-1} + \frac{\delta\chi}{\left(1-\delta\beta\rho_\mu\right)}\left(1-\sigma_c\frac{\gamma}{\alpha}\right)\widehat{\mu}_t.$$

7 References

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