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# COMPETITION AMONG BANKS AND THE PASS-THROUGH OF MONETARY POLICY\*

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## Abstract

This paper introduces monopolistically competitive banks into the New Keynesian DSGE setting. I find that this contributes to explaining three empirical facts: (i) The short-run transmission of changes in monetary policy to bank retail rates is far from complete and heterogeneous. Stiffer competition among commercial banks implies that (ii) retail interest rates correlate more tightly with market rates, and (iii) loan rates exceed the policy rate less. My model predicts that augmented competition in the banking sector reduces the spread between the steady-state policy rate and the loan rate and amplifies the pass-through of monetary policy to the real economy.

**Keywords:** Monopolistically competitive banks; Collateral; External finance premium; Inside money premium

**JEL Classification:** C61; E32; E43; E51

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# 1 Introduction

The present paper examines the impact of an explicitly modelled banking sector on the transmission of shocks, in particular the pass-through of monetary policy. Drawing on Goodfriend and McCallum (2007), I move from a single supplier of financial assets to a monopolistically competitive banking system, where the products of two different banks are imperfect substitutes. Like price-making goods producers, commercial banks can thus set the interest rates they pay on deposits and demand on loans.

There is ample empirical evidence of incomplete pass-through from monetary policy to bank retail rates, at least in the short run. Both loan and deposit rates are found to adjust sluggishly to changes in market interest rates (e.g. Cottarelli and Kourelis (1994), Berlin and Mester (1999), and de Bondt (2005))<sup>1</sup>. A plausible reason for this behaviour are retail rate adjustment costs (Hofmann and Mizen (2004)), as the long-run pass-through is typically estimated to be higher, or almost complete.<sup>2</sup>

In spite of the consensus view that the extent of stickiness differs between countries and bank product categories, the causes are still up for debate. Starting from the seminal theoretical contribution by Klein (1971), a strand of the empirical literature has focused on the relationship between bank competition and monetary transmission. Hannan and Berger (1991) find that deposit rates adjust significantly more sluggishly in concentrated markets, especially when money market rates are rising.

Van Leuvensteijn et al. (2008) analyse the impact of loan market competition on bank rates in the euro area between 1994 and 2004. They find that stronger competition implies lower interest differentials between bank and market rates for most loan products. Moreover, the responsiveness of bank rates to changes in market interest rates is positively correlated with the extent of competition. This agrees with evidence from prior studies using different measures of competition or concentration, including Cottarelli and Kourelis (1994), Borio and Fritz (1995), and de Bondt (2005).<sup>3</sup>

Empirically, stiffer competition from other banks or the capital market seems to speed

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<sup>1</sup>See also Kok Sørensen and Werner (2006) for further euro area evidence and a comprehensive survey of the related literature.

<sup>2</sup>Implicit risk-sharing agreements (Berger and Udell (1992)), where banks shield their customers from fluctuations in market interest rates, and relationship banking (Berger and Udell (1995)) are alternative explanations not considered in this paper.

<sup>3</sup>Certainly, monopolistic competition is just one of several explanations for the observed heterogeneity in interest rate pass-through, but a comparatively robust one (see Sørensen and Werner (2006)).

up the adjustment of retail rates to changes in market conditions. According to Lago-González and Salas-Fumás (2005), a mixture of bank market power and adjustment costs can account for the observed rigidity in retail rates.

Introducing monopolistic competition among banks into a New Keynesian DSGE model has two implications. Relative to a scenario of perfect competition, it leads to an under-provision of deposits and credit contracts, in the long run. While, as a consequence, steady-state economic activity decreases, the real effect is only marginal.

In the short run, incomplete pass-through from the policy rate to deposit and loan rates affects the fluctuations of real variables. Sluggish adjustment of deposit rates amplifies any change in the opportunity cost of consumption and thus the behaviour of output, consumption, and employment at business cycle frequencies.

On the contrary, banks with loan rate setting power have a moderating effect on the fluctuations of real variables. Sticky loan rates cushion the deviation of investment and employment from their respective steady-states, due to a cost channel of monetary policy. At large, the loan market effect clearly dominates the deposit market effect. Monopolistic competition among banks represents thus a significant bottleneck in this model, that reduces the efficiency of monetary policy.

Like Goodfriend and McCallum (2007), my model evolves from a two-sector economy with goods production and banking. Firms use labour and capital to produce a diversified output which is sold in a monopolistically competitive market. They cannot retain earnings, but accumulate productive capital through investment. Returns accrue at the end of period, while the wage bill and investment are paid up front. Firms must therefore finance their production costs by a one-period bank loan.

Commercial banks provide two types of financial intermediation. To produce loans, they combine collateral, consisting of a borrower's productive capital stock and end-of-period profits, with monitoring effort. Since monitoring is costly, banks demand an *external finance premium (EFP)* on top of the risk-free reference rate.

They moreover take deposits from private households. Due to administrative costs, these accounts pay a return below that of a risk-free asset. Households hold them, nevertheless, as they face a deposit-in-advance constraint. Accordingly, I refer to this interest rate differential as the *liquidity premium* or *inside money premium (IMP)*.

Heterogeneity of financial contracts between banks generates an imperfectly competitive market pattern, where the steady states and dynamics of both spreads are affected by the extent of bank competition as well as standard arguments in the marginal costs of deposit and loan provision. By expanding the spreads between policy and retail rates beyond these costs, commercial banks can realise a positive profit.

This paper attempts to overcome the absence or passivity of banks in most models. By allowing financial intermediaries to set interest rates optimally, subject to quadratic adjustment costs à la Rotemberg (1982), I add a micro-founded imperfection to the transmission mechanism of monetary policy. This allows richer dynamics and augments the theoretical findings of Scharler (2008)<sup>4</sup>.

The rest of the paper is organised as follows. Section 2 gives a selective survey of recent related work. Section 3 describes the model. In section 4, I derive the intertemporally optimal behaviour of agents and the symmetric equilibrium. The calibration of parameters and steady-state results are presented in section 5. Section 6 contains a sensitivity analysis of impulse responses to an expansionary monetary policy shock with regard to bank competition. Section 7 concludes.

## 2 Review of Related Literature

The past decade has bred an enormous amount of research on the potential of monetary policy to stimulate and stabilise economic activity. Popular examples of state-of-the-art DSGE models include Christiano et al. (2005), Coenen and Wieland (2005), as well as Smets and Wouters (2003, 2007).

At the same time, the literature disagrees on the importance of money for the conduct of monetary policy. Authors like Ireland (2004) and Woodford (2003) suggest that money plays a minimal role in the business cycle, at best. Yet, these contributions lack financial imperfections which are doubtlessly present in reality. In the light of the current crisis, a standard setting without broad money and credit aggregates, private banks or endogenous interest rates seems increasingly incomplete (see also Beck and Wieland (2007, 2008)).

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<sup>4</sup>Scharler (2008) introduces interest rate adjustment costs into a calibrated sticky price model. He finds that limited interest rate pass-through can in principle reduce the variance of output. However, significant output smoothing comes at the cost of increased inflation volatility.

For this reason, the present paper implements a banking sector in an otherwise standard DSGE model with nominal and real rigidities. It contributes thus to the research initiated by Bernanke and Gertler (1989, 1995), Christiano and Eichenbaum (1995), Carlstrom and Fuerst (1997), Bernanke et al. (1999), Ireland (2003), Goodfriend (2005), and continued more recently by Goodfriend and McCallum (2007), Stracca (2007), as well as Gerali et al. (2008, 2009).<sup>5</sup>

Notably, Goodfriend (2005) distinguishes between narrow money, i. e. currency and bank reserves, and broad money, including bank deposits and highly liquid assets. While the former accommodates automatically when the central bank targets the interest rate, according to the author, broad money must not be ignored in models destined to guide monetary policy.

Goodfriend and McCallum (2007) study the dynamic implications of this approach in a model, where the provision of loans requires collateral as well as monitoring effort. At the same time, transactions presuppose broad money or bank deposits. They identify two opposing effects of a private banking: On the one hand, the well-known “financial accelerator”, resulting from a drop in the value of collateral under adverse economic conditions. This increases the *EFP* and intensifies responses to a given initial disturbance. On the other hand a “banking attenuator”, arising from a fall in consumption during recession. This lowers demand for bank deposits and directs part of borrowers’ net worth into collateral-eligible assets, thereby reducing the *EFP*.

### 3 The Model

The economic environment contains a representative private household, a representative final goods producer, a continuum of intermediate goods-producing firms, a continuum of financial intermediaries, and a monetary authority. Time  $t$  is discrete.

At the beginning of every period, intermediate goods producers take out a loan from one of the private banks to hire labour and to invest into new capital which is productive as of period  $t+1$ . With the borrowed funds, firms produce a differentiated intermediate output that is traded in a monopolistically competitive market.

Banks produce these loans from two substitutable input factors: collateral and labour to

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<sup>5</sup>While all these studies set out to illuminate “the black box” of the credit channel, Ireland (2003) is the first to incorporate a demand for money that facilitates transactions.

screen and monitor borrowers. Since only monitoring is costly, more collateral reduces the cost of providing a loan and thus the loan interest rate demanded by the bank.

A representative final goods producer combines the continuum of intermediate goods to a final good that can be either invested by firms or consumed by the household. The market for final output is perfectly competitive and yields zero profit.

The central bank provides private banks with high-powered money in exchange for risk-free bank bonds which yield a return equal to the central bank-determined policy rate. Monetary policy follows a simple Taylor rule.

A representative household supplies two types of homogeneous labour – work and monitoring effort – to firms and banks, respectively. The real wage is identical across sectors. A constraint forces the household to hold bank deposits for transactions.

Imperfectly competitive agents extract monopolistic rents which are redistributed to the owner, the representative household at the end of period. Likewise, the household receives the central bank's seignorage proceeds. These resources are consumed or saved for future periods in the form of deposits as well as to provide liquidity services.

### 3.1 The Representative Household

The infinitely-lived representative household derives utility from final goods consumption  $c_t$  and from the consumption of leisure time. It maximises discounted lifetime utility

$$E_t \sum_{v=0}^{\infty} \beta^v U_{t+v}, \quad \text{where} \quad U_t = \ln(c_t) + \phi \ln(1 - n_t - s_t). \quad (1)$$

$\beta$  is a subjective discount factor.  $n_t$  and  $s_t$  are the shares of total time endowment, normalised to 1, the household spends working in the firm and the bank, respectively.

Due to asymmetric information in the consumer market, the final goods producer requires an evidence of solvency before delivery. Thus, households must secure an exogenously varying share of consumption by bank deposits  $d$ . This additional restriction is implemented by means of a deposit-in-advance (DIA) constraint in the sense of a standard cash-in-advance (CIA) constraint.<sup>6</sup>

Consumption is paid out of labour income and dividends – distributed by firms and banks – seignorage proceeds transferred by the central bank, and private saving. The

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<sup>6</sup>The DIA constraint is an artificial construct to ensure that deposits are held in equilibrium although they are inferior to the risk-free bank bond with regard to return. Deposits in the utility function would similarly allow for a positive spread between the policy and retail rate (see e. g. Christiano et al. (2009)).

latter either takes the form of deposit accounts at a bank or of financial investment in the risk-free bond  $b$ . Household income that has not been consumed is saved in either asset to raise private wealth. Maximisation is thus subjected to the budget constraint,

$$c_t + b_t + d_t + \frac{\phi_d}{2} \left( \frac{d_t}{d_{t-1}} - 1 \right)^2 d_{t-1} \leq w_t(n_t + s_t) + \frac{d_{t-1}(1 + r_{t-1}^d)}{\pi_t} + \frac{b_{t-1}(1 + r_{t-1})}{\pi_t} + g_t + g_t^f + g_t^{cb}, \quad (2)$$

on the one hand, and to the deposit-in-advance constraint,

$$\alpha_t c_t \leq d_t, \quad \text{with} \quad \alpha_t = \rho_\alpha \alpha_{t-1} + (1 - \rho_\alpha) \alpha + \epsilon_t^\alpha, \quad (3)$$

on the other hand. The DIA constraint embeds an AR(1) process that reverts to a long-run average share of consumption  $\alpha$  to be guaranteed by deposits. Therefore,  $d$  should be interpreted as an aggregate including both sight deposits and cash, or as “highly liquid” assets, in general.  $\epsilon_t^\alpha$  is a Gaussian white noise disturbance.

Deposits yield a gross return  $1 + r^d$ . Any change in the amount of  $d$  gives rise to quadratic adjustment costs. The representative household maximises lifetime utility subject to the above constraints choosing an infinite series of optimal levels of  $\{c_t, n_t, b_t, d_t\}$ .

### 3.2 The Intermediate Goods Sector

The continuum of intermediate goods producers is indexed by  $i \in [0, 1]$ . Firm  $i$  hires homogeneous labour  $n(i)$  from the representative household and produces a differentiated intermediate good  $y(i)$  by means of a common constant returns to scale technology. Selling output in an imperfectly competitive market, intermediate goods producers earn a positive monopolistic profit.

All investment decisions, notably the accumulation of productive physical capital, are in the hands of the firm. The capital accumulation equation takes the usual deterministic form,  $k_t(i) = (1 - \delta)k_{t-1}(i) + i_t(i)$ , where  $i_t(i)$  is gross investment undertaken by firm  $i$  in period  $t$ . Production is described by the Cobb-Douglas function  $y_t(i) = e^{\theta_t} k_{t-1}(i)^\gamma n_t(i)^{1-\gamma}$ , where  $\theta_t = \rho_\theta \theta_{t-1} + \epsilon_t^\theta$  is a persistent disturbance to total factor productivity and  $\epsilon_t^\theta$  a white noise. Note that the period  $t$  capital stock of a firm, which consists of the depreciated  $k_{t-1}$  and recently undertaken investment, will not be productive before the beginning of period  $t + 1$ .

Intermediate goods producers rely on bank loans to finance their current costs up front.



In real terms, firm  $i$  must borrow an amount

$$\frac{L_t(i)}{P_t} = \frac{W_t}{P_t} n_t(i) + \frac{Q_t}{P_t} i_t(i). \quad (4)$$

For simplicity, the typically pro-cyclical market price of capital  $\frac{Q_t}{P_t} = q_t$  is fixed to unity in my model. Final consumption and investment goods are identical, and so are their prices. This largely switches off the “financial accelerator” in the sense of Bernanke et al. (1999). Still, the value of collateral, the demand for monitoring effort, and the *EF*P remain subject to changes in a firm’s stock of physical capital and expected profits – two generally pro-cyclical quantities likely to amplify impulse responses. Note that this assumption is not a prerequisite for solving the model. A market price for capital can be derived by adding a representative capital goods producer who transforms the depreciated old capital stock and final output into new productive capital within a costly investment process.<sup>7</sup>

In equilibrium, default on debt obligations is not an option for firms. The screening activities of commercial banks exclude any would-be borrowers from the loan market right from the start and avoids cases of bankruptcy among intermediate-goods producers.<sup>8</sup>

All firms are owned by the representative household and do not accumulate own funds, apart from the stock of productive capital. At the end of each period, monopolistic profits  $g$  are therefore distributed to the household. The risk-neutral manager of firm  $i$  chooses  $\{n_t(i), P_t(i), k_t(i)\}$  optimally in order to maximise

$$E_t \sum_{v=0}^{\infty} \beta^v \lambda_{t+v} g_{t+v}(i), \quad (5)$$

where real current firm profits are given by

$$\begin{aligned} g_t(i) = & \frac{P_t(i)}{P_t} y_t(i) - \frac{(1 + r_{t-1}^l) [w_{t-1}(i) n_{t-1}(i) + i_{t-1}(i)]}{\pi_t} \\ & - \frac{\phi_p}{2} \left( \frac{P_t(i)}{\pi P_{t-1}(i)} - 1 \right)^2 y_t(i) - \frac{\phi_k}{2} \left( \frac{k_t(i)}{k_{t-1}(i)} - 1 \right)^2 k_{t-1}(i), \end{aligned} \quad (6)$$

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<sup>7</sup>Another version of the model which includes this extension, replicates the “financial accelerator” phenomenon of Bernanke and Gertler (1995) and Bernanke et al. (1999), without, however, influencing the conclusions drawn from the introduction of monopolistically competitive banks. I therefore omit it in the present paper.

<sup>8</sup>This short cut is adopted from Goodfriend and McCallum (2007) who refer to Kocherlakota (1996).

subject to satisfying demand for intermediate good  $i$  by the final goods producer, i. e.

$$e^{\theta_t} k_{t-1}(i)^\gamma n_t(i)^{1-\gamma} \geq \left( \frac{P_t(i)}{P_t} \right)^{-\mu} y_t = y_t(i). \quad (7)$$

The presence of the per-period loan rate  $r^l$  in the profit function (6) introduces a cost channel of monetary policy into the model. Via marginal costs, optimal firm behaviour is directly affected by changes in the policy rate and thus the loan rate.<sup>9</sup>

I assume that monopolistically competitive firms face quadratic adjustment costs when resetting their prices<sup>10</sup> or adjusting the stock of physical capital. Note that the presence of capital adjustment costs implies a value of installed productive capital to the firm that may well lie above  $q$  which has been normalised to unity. As intuition suggests, both price and capital adjustment cost are zero in the stationary equilibrium.

### 3.3 The Final Goods Sector

The representative final goods producer operates in a perfectly competitive market, purchasing  $y(i)$  units of the intermediate good  $i$  at the price  $P(i)$  and assembling these inputs in the usual Dixit-Stiglitz way to produce the final output

$$y_t = \left( \int_0^1 y_t(i)^{\frac{\mu-1}{\mu}} di \right)^{\frac{\mu}{\mu-1}}, \quad (8)$$

where  $\mu$  is the elasticity of substitution between intermediate goods of different producers. The profit-maximising demand of the final goods-producing firm for intermediate good  $i$  is thus  $y_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{-\mu} y_t$ , with an aggregate price index  $P_t = \left( \int_0^1 P_t(i)^{1-\mu} di \right)^{\frac{1}{1-\mu}}$ .

### 3.4 The Financial Intermediaries Sector

Commercial banks – indexed  $j \in [0, 1]$  – provide slightly differentiated financial products. They face a constant finite elasticity of substitution in the market for deposits and loans, respectively, where they compete in their interest rates. In line with Gerali et al.

<sup>9</sup>For an overview of the related literature and a theoretical analysis of the relevance of the cost channel, see Henzel et al. (2009).

<sup>10</sup>The deferred repayment of working capital loans overly complicates the computation of an expression for real marginal costs. I therefore preferred quadratic price adjustment costs according to Rotemberg (1982) to the more popular price stickiness à la Calvo (1983). Note that both approaches deliver equivalent optimal price-setting behaviour of monopolistically competitive goods producers, which has been proven e. g. by Roberts (1995).

(2008, 2009), I assume that customers demand a Dixit-Stiglitz composite of the above differentiated contracts. Formally, this means that the representative household divides its deposit holdings across the entire continuum of banks. Similarly, firms must sign loan contracts with each bank in order to raise one unit of external funds. Although the story behind this micro-founded approach is far from realistic, it incorporates the crucial features for analysing the impact of bank competition on the pass-through of monetary policy.<sup>11</sup> As a consequence, bank  $j$  faces a downward-sloping demand curve  $l_t(j) = \left(\frac{r_t^l(j)}{r_t^l}\right)^{-\eta_l} l_t$  for loans and an upward-sloping demand curve  $d_t(j) = \left(\frac{r_t^d(j)}{r_t^d}\right)^{\eta_d} d_t$  for deposit accounts (see also Henzel et al. (2009), Gerali et al. (2008, 2009)). The responsiveness of a bank's share in the composite deposit and loan contract to the corresponding interest rate depends inversely on the CES parameters  $\eta_d$  and  $\eta_l$ .

When resetting interest rates, banks bear Rotemberg (1982) adjustment costs. Similar to the case of a price-setting firm, the latter should be considered as “menu costs”. In particular, they cover any resource costs related to communicating the new retail rates. Bank  $j$  produces loans according to the CRS function

$$l_t(j) = F(g_t + qk_t)^\sigma (e^{\chi_t} s_t(j))^{1-\sigma}, \quad (9)$$

where monitoring effort  $s_t$ , supplied by the representative household, is the only costly input factor. I assume that all banks are of comparable size and have an identical number of clients which are distributed randomly across financial institutions. Subject to these simplifications, the monitoring required to provide a line of credit  $l(j)$  depends inversely on the level of economy-wide collateral.<sup>12</sup>

Collateral consists of current period profits, on the one hand, which are only distributed to the household after a firm has honoured its debt. On the other hand, the bank seizes the borrower's capital stock in the event of default, excluded in this model.

Since  $k$  is installed in the firm, only a constant fraction  $q < 1$  is considered actually

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<sup>11</sup>Approaches with a richer economic content are taken e. g. by Andrés and Arce (2008). They use a version of Salop's (1979) circular city to model imperfect competition in the loan market, where borrowers suffer a utility cost when travelling to a bank. Aliaga-Díaz and Oliveiro (2007) introduce switching costs à la Klemperer (1995) as a source of market power. These costs lead to a bank client “lock-in” effect.

<sup>12</sup>While an influence of firm-specific collateral on the cost of external funding seems more realistic, I make this simplifying assumption to avoid an additional channel of monetary transmission. Feedback from the loan interest rate into individual firm's optimal investment and production decisions would create an incentive to exert influence on  $r^l$  by accumulating excess capital. In the symmetric equilibrium, the assumption of economy-wide collateral is entirely unproblematic.

collectible by the bank.<sup>13</sup>  $\chi_t = \rho_\chi \chi_{t-1} + \epsilon_t^\chi$  is an auto-correlated innovation to monitoring technology, in the following referred to as *external finance premium shock* or *EFP shock*, with  $\epsilon_t^\chi$  i.i.d. normal.

In addition, bank  $j$  provides deposits to the household. The associated costs  $\frac{\omega_t d_t(j)}{m_t(j)}$  rise with the amount of  $d$  and fall in the bank's reserves of central bank money. Banks expand their reserves  $m_t(j)$  by engaging in an open market operation. They issue a risk-free bond  $b$  which is bought by the monetary authority in exchange for high-powered money. The mean-reverting marginal cost  $\omega_t = \rho_\omega \omega_{t-1} + (1 - \rho_\omega)\omega + \epsilon_t^\omega$  is not idiosyncratic. It fluctuates around a long-run average value of  $\omega$ , disturbed by a white noise shock  $\epsilon_t^\omega$ , later on referred to as the *inside money premium shock* or *IMP shock*.

In open market operations, private banks can borrow without restraint at the risk-free rate  $r$ , set by the central bank. They will thus not agree to pay a return on sight deposits above the policy rate, corrected for the cost of deposit provision. The difference between  $r_t$  and  $r_t^d$  is a liquidity premium, called the *inside money premium (IMP)* below.

The risk-neutral manager of bank  $j$  sets  $\{d_t(j), s_t(j), b_t(j), m_t(j), r_t^d(j), r_t^l(j)\}$  to maximise

$$E_t \sum_{v=0}^{\infty} \beta^v \lambda_{t+v} g_{t+v}^f(j), \quad (10)$$

where instantaneous profits are

$$\begin{aligned} g_t^f(j) = & d_t(j) + b_t(j) + \frac{m_{t-1}(j)}{\pi_t} + \frac{l_{t-1}(j)(1 + r_{t-1}^l(j))}{\pi_t} - l_t(j) - m_t(j) \\ & - \frac{d_{t-1}(j)(1 + r_{t-1}^d(j))}{\pi_t} - \frac{b_{t-1}(j)(1 + r_{t-1})}{\pi_t} - w_t s_t(j) - \frac{\omega_t d_t(j)}{m_t(j)} \\ & - \frac{\phi_{r^d}}{2} \left( \frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2 d_t(j) - \frac{\phi_{r^l}}{2} \left( \frac{r_t^l(j)}{r_{t-1}^l(j)} - 1 \right)^2 l_t(j), \end{aligned} \quad (11)$$

subject to  $d_t(j) \geq \left( \frac{r_t^d(j)}{r_t^d} \right)^{\eta_d} d_t$  and  $l_t(j) \geq \left( \frac{r_t^l(j)}{r_t^l} \right)^{-\eta_l} l_t$ .

The two demand constraints result from an optimal deposit placement of the representative household and from a cost-minimising borrowing behaviour of intermediate goods producers, respectively.

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<sup>13</sup>The real market price of the uninstalled physical capital would then again equal 1, as it is identical in its characteristics to the final output good.

### 3.5 The Monetary Authority

This paper abstains from modeling a government or any fiscal policy. Yet, I introduce an authority exercising monetary policy. Its highly stylised balance sheet contains merely high-powered money  $m$  on the liabilities side and bank bonds  $b$  on the asset side.

Every period, the monetary authority conducts open market operations to provide commercial banks with their desired amount of central bank money in exchange for risk-free bank bonds. Since its assets  $b$  yield a return, namely the monetary policy rate, while its liability  $m$  doesn't, the central bank retains a positive seignorage profit from open market operations<sup>14</sup>:

$$g_t^{cb} = m_t + \frac{b_{t-1}(1 + r_{t-1})}{\pi_t} - b_t - \frac{m_{t-1}}{\pi_t}. \quad (12)$$

To avoid that these proceeds are lost to the economy, I assume that they are transferred to the representative household as an additional source of non-labour income.

Monetary policy follows a simple version of the standard Taylor (1993) rule:

$$r_t = (1 - \rho)(\beta^{-1} - 1 + \varphi_\pi(\pi_t - 1)) + \rho r_{t-1} + \epsilon_t^r. \quad (13)$$

The risk-free nominal interest rate adjusts to offset any deviations of current inflation from its target value.<sup>15</sup> In a stationary environment, it is reasonable to assume that the central bank targets strict price stability, i. e. a zero inflation rate. The rule also incorporates interest rate inertia, capturing a strong aversion to fluctuations in the policy instrument ( $0 < \rho < 1$ ).

The Taylor principle for stability is fulfilled, if the monetary authority raises the real interest rate in response to an inflationary shock. This holds when  $\varphi_\pi > 1$ . The white noise shock  $\epsilon_t^r$  is beyond control and prevents an exact pursuit of the policy rule.

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<sup>14</sup>A rise in the policy rate increases thus the cost of holding reserves of financial intermediaries as well as the seignorage profit of the central bank.

<sup>15</sup>Alternative Taylor rules, e.g. embedding a reaction to the so-called output gap, do not change neither qualitative nor quantitative results significantly, as long as empirically reasonable values for the monetary policy parameters are chosen.

## 4 Intertemporal Optimisation of Agents

### 4.1 Household Utility Maximisation

The first order conditions (FOCs), resulting from the representative household's optimisation problem, with respect to its choice variables  $c_t$ ,  $n_t(s_t)$ ,  $b_t$ , and  $d_t$  are:

$$\frac{1}{c_t} = \lambda_t + \xi_t \alpha_t \quad (14)$$

$$\frac{\phi}{1 - n_t - s_t} = \lambda_t w_t \quad (15)$$

$$\lambda_t = \beta E_t \lambda_{t+1} \frac{1 + r_t}{\pi_{t+1}} \quad (16)$$

$$\begin{aligned} \left(1 + \phi_d \left(\frac{d_t}{d_{t-1}} - 1\right)\right) \lambda_t &= \beta E_t \lambda_{t+1} \left[ \phi_d \left(\frac{d_{t+1}^2}{d_t^2} - \frac{d_{t+1}}{d_t}\right) - \frac{\phi_d}{2} \left(\frac{d_{t+1}}{d_t} - 1\right)^2 \right] \\ &\quad + \beta E_t \lambda_{t+1} \frac{1 + r_t^d}{\pi_{t+1}} + \xi_t. \end{aligned} \quad (17)$$

$\lambda$  and  $\xi$  are the Lagrange multipliers of the budget and the DIA constraint, respectively. Together with the latter, these 4 equations determine optimal household behaviour.

### 4.2 Profit Maximisation of Intermediate Goods Producers

The corresponding FOCs of the monopolistically competitive firm  $i$  with respect to  $n_t(i)$ ,  $P_t(i)$ , and  $k_t(i)$ , respectively, are:

$$\beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}} (1 + r_t^l) w_t = (1 - \gamma) \Xi_t(i) \frac{y_t(i)}{n_t(i)} \quad (18)$$

$$\begin{aligned} (1 - \mu) \lambda_t + \mu \Xi_t(i) + \mu \lambda_t \frac{\phi_p}{2} \left(\frac{\pi_t}{\pi} - 1\right)^2 &= \\ \lambda_t \phi_p \left(\frac{\pi_t^2}{\pi^2} - \frac{\pi_t}{\pi}\right) - \beta E_t \lambda_{t+1} \phi_p \left(\frac{\pi_{t+1}^2}{\pi^2} - \frac{\pi_{t+1}}{\pi}\right) \frac{y_{t+1}}{y_t} \end{aligned} \quad (19)$$

$$\begin{aligned} \beta^2 E_t \lambda_{t+2} \frac{(1 + r_{t+1}^l)(1 - \delta)}{\pi_{t+2}} - \beta E_t \lambda_{t+1} \frac{(1 + r_t^l)}{\pi_{t+1}} &= -\beta E_t \lambda_{t+1} \phi_k \left( \left(\frac{k_{t+1}(i)}{k_t(i)}\right)^2 - \frac{k_{t+1}(i)}{k_t(i)} \right) \\ + \lambda_t \phi_k \left( \frac{k_t(i)}{k_{t-1}(i)} - 1 \right) - \beta \gamma E_t \Xi_{t+1}(i) \frac{y_{t+1}(i)}{k_t(i)} &+ \beta E_t \lambda_{t+1} \frac{\phi_k}{2} \left( \frac{k_{t+1}(i)}{k_t(i)} - 1 \right)^2, \end{aligned} \quad (20)$$

where  $\Xi(i)$  is the Lagrange multiplier of firm  $i$ 's requirement to satisfy demand at the chosen price. These conditions are completed by the capital accumulation equation and the Cobb-Douglas production function.

### 4.3 Profit Maximisation of Financial Intermediaries

The optimal behaviour of bank  $j$  is prescribed by the following FOCs with respect to  $d_t(j)$ ,  $b_t(j)$ ,  $s_t(j)$ , and  $m_t(j)$ :

$$\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{(1 + r_t^d(j))}{\pi_{t+1}} + \frac{\omega_t}{m_t(j)} - 1 = \frac{\lambda_t^d(j)}{\lambda_t} - \frac{\phi_{rd}}{2} \left( \frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2 \quad (21)$$

$$1 = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{(1 + r_t)}{\pi_{t+1}} \quad (22)$$

$$\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{(1 + r_t^l(j))}{\pi_{t+1}} + \frac{\lambda_t^l(j)}{\lambda_t} - 1 = \frac{w_t s_t(j)}{(1 - \sigma) l_t(j)} + \frac{\phi_{rl}}{2} \left( \frac{r_t^l(j)}{r_{t-1}^l(j)} - 1 \right)^2 \quad (23)$$

$$\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{\pi_{t+1}} = 1 - \frac{\omega_t d_t(j)}{m_t(j)^2}, \quad (24)$$

where the multipliers of its deposit and loan demand constraints are  $\lambda_t^d(j)$  and  $\lambda_t^l(j)$ . By combining (21) and (22), we receive an expression for the *inside money premium*, i.e. the spread between the risk-free interest rate and the return on deposits at bank  $j$ .

$$IMP_t: \quad E_t \frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} (r_t - r_t^d(j)) = \frac{\omega_t}{m_t(j)} - \frac{\lambda_t^d(j)}{\lambda_t} + \frac{\phi_{rd}}{2} \left( \frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2$$

This interest differential is determined by the marginal cost of deposit provision (the first term on the right hand side), the marginal cost in terms of household utility of a loss of clients who dissolve their accounts at the bank (the second term on the right hand side) and quadratic interest rate adjustment costs (the third term on the right hand side).

Equivalently, we may substitute from (22) into the first-order condition w.r.t. monitoring (23) to obtain an expression for the *external finance premium*. It quantifies the opportunity cost of firms when relying on bank loans, i. e. external funds.

$$EFP_t: \quad E_t \frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} (r_t^l(j) - r_t) = \frac{w_t s_t(j)}{(1 - \sigma) l_t(j)} - \frac{\lambda_t^l(j)}{\lambda_t} + \frac{\phi_{rl}}{2} \left( \frac{r_t^l(j)}{r_{t-1}^l(j)} - 1 \right)^2$$

The meaning of the right hand side terms is corresponding: The marginal cost of an additional unit of monitoring effort, the change in utility terms of a gain or loss in loan market share, and the quadratic costs of adjusting the loan interest rate. I finally merge (24) and (22) to derive an explicit demand for central bank money  $m$ :

$$E_t \frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} r_t = \frac{\omega_t d_t(j)}{m_t(j)^2} \quad \Leftrightarrow \quad m_t(j) = \sqrt{\frac{\omega_t d_t(j)}{\beta r_t E_t(\frac{1}{\pi_{t+1}})}}$$

In open market operations, commercial banks have no influence on the policy rate  $r$ . Neither do they face adjustment costs. Bank  $j$  will thus accumulate reserves until the marginal product of  $m$  in deposit provision equals the difference between the central bank-determined interest rate and the return on high-powered money.

These optimality conditions are completed by the loan production function and the firm's credit requirement. I thus assume that demand for loans is satisfied in equilibrium.

In similar form, the above expressions also arise in a framework with fully competitive banks. Monopolistic competition among private banks adds two new decision variables. Deposit and loan interest rates are set in the face of adjustment costs and a proportional loss of clients. Accordingly, the optimal values of  $r_t^d$  and  $r_t^l$ , respectively, must fulfil the following first-order conditions:

$$\begin{aligned} & \lambda_t \eta_d \left( \frac{r_t^d(j)}{r_t^d} \right)^{\eta_d-1} \frac{d_t}{r_t^d} \left[ 1 - \frac{\omega_t}{m_t(j)} \right] - \beta E_t \lambda_{t+1} \frac{d_t}{\pi_{t+1}} \left( \frac{r_t^d(j)}{r_t^d} \right)^{\eta_d-1} \left[ \eta_d \frac{1 + r_t^d(j)}{r_t^d} + \frac{r_t^d(j)}{r_t^d} \right] \\ & - \lambda_t \phi_{r^d} \left( \frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right) \left( \frac{r_t^d(j)}{r_t^d} \right)^{\eta_d} \frac{d_t}{r_{t-1}^d(j)} + \beta E_t \lambda_{t+1} \phi_{r^d} \left( \frac{r_{t+1}^d(j)}{r_t^d(j)} - 1 \right) \left( \frac{r_{t+1}^d(j)}{r_{t+1}^d} \right)^{\eta_d} \frac{r_{t+1}^d(j)}{r_t^d(j)^2} d_{t+1} \\ & - \lambda_t \eta_d \frac{\phi_{r^d}}{2} \left( \frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2 \left( \frac{r_t^d(j)}{r_t^d} \right)^{\eta_d-1} \frac{d_t}{r_t^d} - \lambda_t^d \eta_d \left( \frac{r_t^d(j)}{r_t^d} \right)^{\eta_d-1} \frac{d_t}{r_t^d} = 0 \end{aligned} \quad (25)$$

$$\begin{aligned} & \lambda_t \eta_l \left( \frac{r_t^l(j)}{r_t^l} \right)^{-\eta_l-1} \frac{l_t}{r_t^l} - \beta E_t \lambda_{t+1} \frac{l_t}{\pi_{t+1}} \left( \frac{r_t^l(j)}{r_t^l} \right)^{-\eta_l-1} \left[ \eta_l \frac{1 + r_t^l(j)}{r_t^l} - \frac{r_t^l(j)}{r_t^l} \right] \\ & - \lambda_t \phi_{r^l} \left( \frac{r_t^l(j)}{r_{t-1}^l(j)} - 1 \right) \left( \frac{r_t^l(j)}{r_t^l} \right)^{-\eta_l} \frac{l_t}{r_{t-1}^l(j)} + \beta E_t \lambda_{t+1} \phi_{r^l} \left( \frac{r_{t+1}^l(j)}{r_t^l(j)} - 1 \right) \left( \frac{r_{t+1}^l(j)}{r_{t+1}^l} \right)^{-\eta_l} \frac{r_{t+1}^l(j)}{r_t^l(j)^2} l_{t+1} \\ & + \lambda_t \eta_l \frac{\phi_{r^l}}{2} \left( \frac{r_t^l(j)}{r_{t-1}^l(j)} - 1 \right)^2 \left( \frac{r_t^l(j)}{r_t^l} \right)^{-\eta_l-1} \frac{l_t}{r_t^l} + \lambda_t^l \eta_l \left( \frac{r_t^l(j)}{r_t^l} \right)^{-\eta_l-1} \frac{l_t}{r_t^l} = 0 \end{aligned} \quad (26)$$

It is straightforward to simplify these equations, dividing by the marginal utility of household consumption,  $\lambda_t$ , and by the economy-wide average levels of sight deposits,  $d_t$ , and loan contracts,  $l_t$ , as well as multiplying them by  $r_t^d$  and  $r_t^l$ , respectively.



## 4.4 The Symmetric Equilibrium

The competitive equilibrium is an infinite sequence of the endogenous model variables, where all economic agents optimise, the monetary authority follows the Taylor rule, and goods as well as financial contract markets clear.

I assume that the representative household holds zero bonds in equilibrium and accumulates financial wealth only in terms of bank deposits. Apart from that, the equilibrium conditions of the household and the central bank basically replicate their FOCs. The same is true for the monopolistically competitive firms and banks.

Although the latter two agents profit from quantifiable market power which allows each firm  $i$  to set its price and each bank  $j$  to set its interest rates independently, I assume symmetric behaviour in the following. Facing the same economic state and only aggregate innovations<sup>16</sup>, their factor demand and price-setting decisions will be identical in equilibrium. Under the above symmetry assumptions, I receive a system of 23 equations contained in Appendix A.

## 5 Calibration and Steady-State Analysis

From Appendix A, it is straightforward to derive the stationary equilibrium. I assume the absence of shocks in the steady state, so that  $\epsilon^r = 0$  and the exogenous variables  $\alpha_t$ ,  $\omega_t$ ,  $\theta_t$ ,  $\chi_t$  adopt their long-run trend values  $\alpha$ ,  $\omega$ ,  $\theta$ ,  $\chi$ , where the latter two equal zero. Due to the nonlinear nature of the model, there is no closed form analytical solution. Instead, it is solved numerically by the Gauss-Newton method in MATLAB.

As far as possible, I calibrate the parameter set according to the existing literature, see e.g. King and Rebelo (1999), Smets and Wouters (2003), and Christiano et al. (2005). When it comes to banking-related parameters, prior sources of information are rare. The calibration is thus geared to generate empirically relevant steady-state values of key financial variables – especially of bank interest rates and spreads.

### 5.1 Choice of Parameter Values

The household discount factor  $\beta$  is set to a quarterly value of 0.995 to match the average inflation-adjusted Effective Federal Funds Rate between 1985 and 2009. This corre-

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<sup>16</sup>Remember that the model does not incorporate idiosyncratic shocks to any of the economic agents.

sponds to a real annual policy rate of 2%. With a weight of leisure  $\phi = 1.43$  in the utility function, the representative household spends one third of its total time endowment working in either firms or banks. On average, the household must secure 80% of consumption by bank deposits ( $\alpha = 0.8$ ).

I set the income share of capital in goods production  $\gamma$  to a standard value of 0.35. Productive capital depreciates with a quarterly rate  $\delta$  of 2.5%. A price elasticity of demand for intermediate goods  $\mu = 6$  implies a monopolistic mark-up of 20% over marginal costs in the steady-state.

Collateral is relatively more efficient in loan production than in goods production. The higher a borrower's guarantee, the less informational effort must be invested by banks to provide a given amount of credit and to ensure its repayment. Without collateral, no loans can be produced, at all. Similar to Goodfriend and McCallum (2007), I set  $\sigma$ , the contribution of collateral in the loan production function, equal to 0.6.

Installed physical capital is considered recoverable and marketable only to an extent  $q$  of 20%. A constant TFP  $F = 6$  completes the set of loan production parameters. They are calibrated to the average US Prime Lending Rate between 1985 and 2009.

The stationary equilibrium value of the deposit interest rate is highly sensitive to marginal administration costs. To obtain a reasonable differential,  $\omega$  is kept very low.<sup>17</sup>

I finally calibrate the interest-rate elasticities of deposit and loan demand. Both  $\eta_d$  and  $\eta_l$  are not yet well-established in the New Keynesian literature, where Gerali et al. (2009) and Henzel et al. (2009) are the only sources of reference known to the author.<sup>18</sup> Setting  $\eta_d = 5$  and  $\eta_l = 7$ , I implicitly assume that banks face a higher elasticity of substitution in the loan market. As a consequence, they demand a lower markup over marginal costs.<sup>19</sup> Moreover, banks and firms enjoy comparable levels of market power, in this setting.

Lacking microeconomic evidence, these two CES parameters are the most obvious source of vagueness in my calibration. I do not claim to set a benchmark, here, at all.

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<sup>17</sup>Increasing the parameter  $\omega$  easily leads to a negative real interest rate paid on household deposit. Although this is imaginable when considering nominal interest rates on checking or overnight deposit accounts and correcting for inflation, I choose a calibration with positive steady-state real return on all financial assets.

<sup>18</sup>In both papers, the interest elasticity of loan demand by firms is set to 3.5. Gerali et al. (2009) furthermore choose values of 5.1 for loans to households and -1.3 for deposits. A negative elasticity of substitution implies a markdown on the deposit rate, due to an upward sloping demand curve.

<sup>19</sup>This calibration is motivated by the seemingly stronger ties between commercial banks and private households as depositors (compare e. g. van Leuvensteijn et al. (2008)).

## 5.2 The Stationary Equilibrium

As announced in the introduction to this chapter, the model is now solved numerically. Under the above parameterisation, I obtain the steady-state values listed in table 1.

Several intuitive results follow directly. With a value of 2.42, the annual capital-output ratio is low but in an acceptable range. A consumption-to-GDP ratio  $c/y$  of 0.757 and an investment-to-GDP ratio  $i/y$  of 0.242 indicate that household consumption and firm investment absorb the lion's share of output, but not all. 0.14% of GDP is spent on the administration of deposits. These costs are sunk and not redistributed to bank employees in the form of wages or to the owners of deposits as interest payment. Remember that this is not the case in loan production, where only monitoring is costly. While monitoring reduces bank profits and thus the dividend distributable to households, it simultaneously raises the salary of the latter. Both banks and firms earn a positive monopolistic rent in the steady state.

The stationary equilibrium applies for a period length of one quarter and zero inflation. Thus,  $r$ ,  $r^d$ , and  $r^l$  imply an annual real interest on risk-free bonds (the policy rate), sight deposits, and loans of about 2%, 1%, and 4.6%. This corresponds to a steady-state annual *IMP* of 100 basis points and a steady-state annual *EFP* of 2.62%.

What I label *premium* is indeed the consequence of two special features of this model. On the one hand, there is an intermediation cost in both the deposit and the loan market that is passed on to clients. Private banks demand an interest rate above the risk-free rate on working capital loans and pay an interest rate below  $r$  on deposit accounts. On the other hand, imperfect competition among banks allows them to expand these interest differentials. The monopolistic mark-ups or mark-downs in  $r^d$  and  $r^l$ , respectively, generate positive steady-state profits.

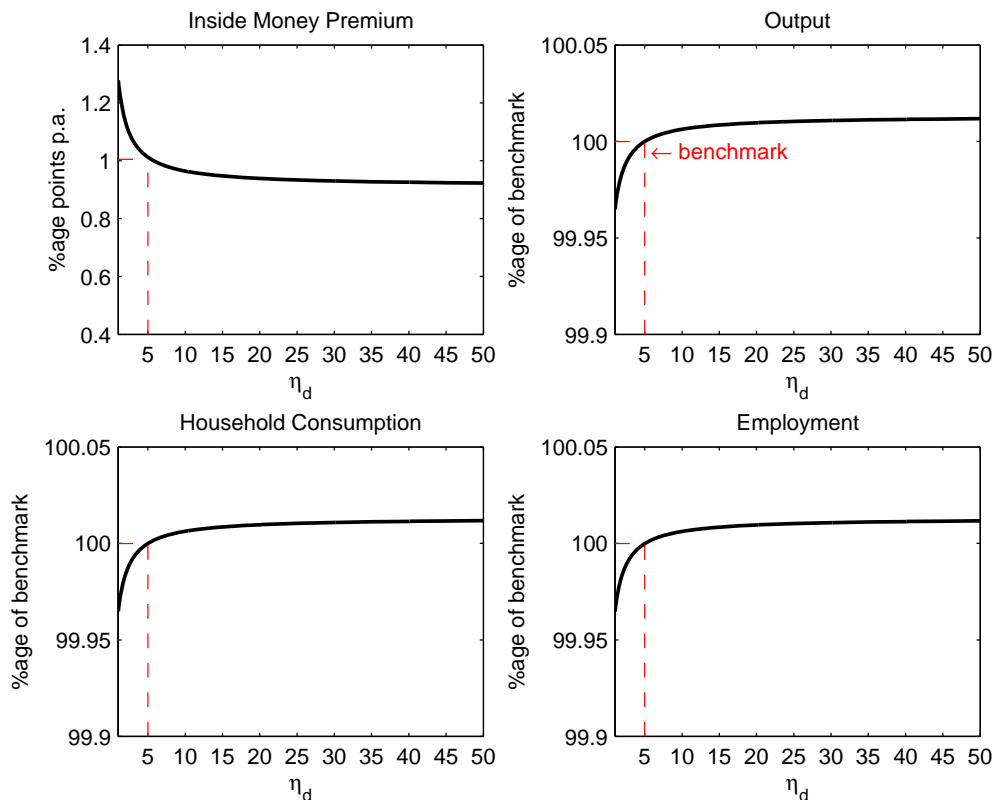
Steady-State Values ( <i>benchmark calibration</i> )								
$y$	$c$	$i$	$k$	$n$	$s$	$r$	$r^d$	$r^l$
1.1224	0.8500	0.2708	10.8323	0.3311	0.0022	0.0050	0.0025	0.0116
$w$	$d$	$m$	$l$	$g$	$g^f$	$\pi$	<i>IMP</i>	<i>EFP</i>
1.8242	0.6800	0.3085	0.8748	0.2374	0.0024	1.0000	0.0025	0.0066

**Table 1:** Steady-state results for a benchmark parameter calibration

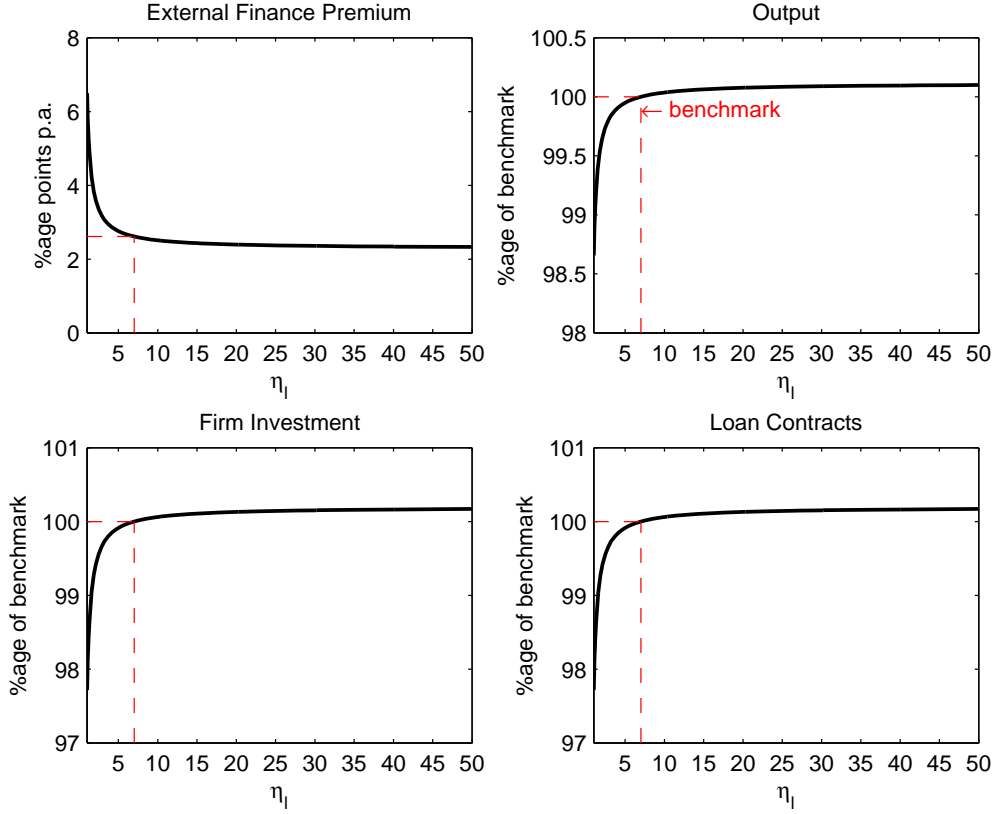
### 5.3 Comparative Statics

The steady-state values presented in table 1 primarily serve as a guideline for an adequate calibration and lack illustrative power without further study. The question is thus nearby, how long-run economic activity in this model depends on the extent of competition among banks. For this purpose, I analyse the steady-state values of a few selected variables with respect to the interest rate sensitivities  $\eta_d$  and  $\eta_l$ .

Figure 1 illustrates the long-run relation between economic activity and competition in the market for deposits. Therein, I steadily increase the parameter of interest from above 1, i. e. hardly any substitution, to 50, approximating perfect competition among the providers of deposits contracts. Obviously, output, investment and employment are negatively correlated with bank market power. The smaller is  $\eta_d$  and the less sensitive the demand for deposits of bank  $j$  to  $r_t^d(j)$ , the higher is the mark-up demanded on top of marginal costs and the *IMP*.



**Figure 1:** Imperfect competition on the deposit market for values of  $\eta_d \in (1, 50]$



**Figure 2:** Imperfect competition in the market for loans,  $\eta_l \in (1, 50]$

In the case of extremely low competition, the spread between the policy and the bank rate climbs to a maximum of about 1.3 percentage points p. a.. Even when approaching the lower boundary of relevant CES coefficients, the impact on economic activity is negligible. It leads to a contraction relative to the benchmark steady state of below 5 basis points in each output, consumption, and employment. Economic activity expands by even less in the absence of market power.<sup>20</sup> This implies that market imperfections stemming from monopolistic competition in the bank deposit sector do not result in a significant long-run loss of efficiency, in this model.

Accordingly, figure 2 illustrates the stationary levels of economic activity as a percentage of the benchmark case for different levels of competition in the market for loans. When  $\eta_l$  converges to 1, banks drive the *EFP* up to an annual value of 6.5 percentage points. This still appears to be a moderate markup. As a consequence, the steady state of

<sup>20</sup>Note that even in the case of perfect competition, the *IMP* does not drop to zero, as banks still face positive costs of deposit provision.

output contracts by 1.4% relative to its benchmark value. Investment into productive capital and the amount of loans even shrink by up to 2.3%. Again, the expansionary effect of an above-benchmark level of competition is comparatively small, reaching values of 0.1% for output, and 0.17% for investment and loans. Eliminating the market power of lenders reduces the *external finance premium* by only 30 basis points p.a..

In line with the first finding of van Leuvensteijn et al. (2008), imperfect competition among financial intermediaries leads to increased spreads between bank retail rates and the policy rate. By causing an under-provision of economic agents with liquidity and working capital loans, bank market power constrains long-run economic activity. In an environment with monopolised markets for financial services, the model predicts a reduction in output, consumption, employment, and investment below their potential steady-state equilibrium values under perfect competition. While this reduction is more pronounced in the loan sector, by and large, the market imperfections seem unimportant, notably for the benchmark calibration as a relevant guideline.

## 6 Dynamic Analysis

In the following sections, the model is solved by numerical simulation in order to examine whether it is able to reproduce the empirically predicted impulse responses to standard exogenous shocks. Moreover, I analyse how the level of competition among corporate banks affects the transmission mechanism and thus the efficiency of monetary policy.

### 6.1 Remaining Parameters

When calibrating the model for the steady-state analysis, irrelevant parameters were left open. On the one hand, this concerns the entire set of adjustment cost coefficients, since quadratic adjustment costs have the convenient trait of disappearing in the steady state. The estimates in the related literature for the capital adjustment cost coefficient  $\phi_k$  range from 10 to 35, depending on the respective model specifications and data sample period. Following Ireland (2003) who receives a highly significant  $\phi_k$  of 32.13 in a sticky price model for the post-1979 period, I pick a value of 35. I further set the coefficient of price rigidity  $\phi_p$  to 100, a value in the mid range of Ireland's estimates. Adjusting deposits is assumed to be less costly than adjusting a firm's capital stock, i. e.  $\phi_d = 30$ .

The empirical evidence for the remaining adjustment cost coefficients,  $\phi_{r,d}$  and  $\phi_{r,l}$ , is rather limited. It seems acceptable to render it equally costly for a bank to change its interest rate as it is for a firm to change its price.<sup>21</sup> With regard to the different measures of price – which is a numéraire, here – and interest rate, as well as the steady-state values of retail rates per quarter, I therefore set  $\phi_{r,d} = 0.25$  and  $\phi_{r,l} = 1$ .

On the other hand, the Taylor rule must be specified numerically. It is characterised by an exclusive reaction to deviations from the zero target inflation rate and by interest-rate inertia. The central bank is averse to sudden jumps in the policy rate and places a weight  $\rho = 0.75$  on  $r_{t-1}$ . To satisfy the Taylor principle, the central bank must raise the nominal interest rate by more than one percentage point for each percentage point increase in inflation. In line with Taylor’s original proposal, I set  $\varphi_\pi$  to 1.5.<sup>22</sup>

Finally, I calibrate the autoregressive coefficients and standard deviations of the four shocks. Following Ireland (2003) and many others, I assume that these processes display a significant persistence, with  $\rho_\alpha = 0.88$ ,  $\rho_\theta = 0.95$ ,  $\rho_\chi = 0.9$ , and  $\rho_\omega = 0.9$ . For the associated standard deviations of the i.i.d. disturbances, I choose  $\sigma_\alpha = 0.6$ ,  $\sigma_\theta = 0.8$ ,  $\sigma_\chi = 0.8$ , and  $\sigma_\omega = 0.18$  in percentage terms. These parameters imply that technology shocks in the banking and the goods-producing sector are similarly highly auto-correlated and of same average magnitude.

The standard deviation of monetary policy shocks  $\sigma_r$  is set to 25 basis points on a quarterly basis. This corresponds to an innovation in the policy rate of one percentage point per annum. Table 2 provides an overview of the entire set of benchmark parameter values.

## 6.2 Results

The dynamic system of equations is solved with DYNARE on MATLAB. I loglinearise the model at the steady state, since the solution algorithm requires linearity. Appendix B contains the transformed system of equilibrium conditions.

The simulation results are presented in two steps, beginning with the impulse responses

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<sup>21</sup>Gerali et al. (2009) estimate quadratic adjustment cost coefficients for bank retail rates, receiving posterior mean values of 10.13 for household deposit and 14.1 for loans to firms. In my model setting, where adjustment costs are proportional to bank  $j$ ’s amounts of deposits and loans but not weighted by the respective rates, this would approximately correspond to  $\phi_{r,d} = 0.06$  and  $\phi_{r,l} = 0.25$ .

<sup>22</sup>Note that a calibration with  $\varphi_\pi \leq 1$  does not satisfy the stability conditions for applying the solution method proposed by Blanchard and Kahn (1980). In this case, the equilibrium becomes indeterminate.

of a selection of important variables to the model's exogenous shocks. The subsequent sensitivity analysis focuses on the importance of monopolistic competition among commercial banks for the transmission of monetary policy.

### 6.2.1 Impulse Responses in the Benchmark Model

This section provides a survey of the model's implications for the dynamic behaviour of key economic variables over the business cycle. The corresponding impulse response functions are displayed at the end of the paper.

#### Technology shock

Figure 5 maps the reaction of selected variables to a one-standard-deviation shock to the technology parameter  $\theta$ . It generates the empirically found hump-shaped responses in output, consumption, and investment. Output takes two years before it peaks at 0.53 percent above its stationary equilibrium and starts to converge back. Restricted by deposits which are costly to adjust, consumption reacts equally slowly. It reaches a maximum percentage deviation from steady state of 0.495 after 9 quarters, only.

Investment, on the contrary, responds much quicker and increases by more than 1.5 times this fraction. As in the data, it displays thus the highest variability of the three. Due to a strong rise in the real wage, employment in goods production falls on impact. Over time, additional physical capital is accumulated and the growth in labour productivity justifies the payment of a higher real wage.

The monetary authority responds to the slowdown in inflation by 0.13 percentage points, and mechanically relaxes its policy. At the end of the first year, the quarterly risk-free interest rate has fallen by 8.2 basis points. This corresponds to roughly 0.33 percent on an annual basis.

The technology shock spills over to the banking sector, as well. The immediate rise in desired investment is financed through additional loans. Employment in the banking sector increases, accordingly. While the direction of the overall changes in  $r^d$  and  $r^l$  is predetermined by the policy rate, the effect of the exogenous shock is visible in the *IMP* and *EFP*. With decreasing marginal productivity of monitoring effort, the expansion of loan production raises marginal costs. Thus, banks demand a higher premium on top of the risk-free rate.



Although more deposits are required, as consumption rises with economic activity, banks are able to provide them at a reduced cost. Their increased demand for high-powered money  $m$  is amplified by the expansionary monetary policy. Temporarily, the quarterly inside money premium falls by up to 5 basis points.

### Monetary Policy shock

As a next step, I analyse an unforeseen increase in the annual policy rate by one percentage point, i. e. a positive disturbance of 25 basis points to the Taylor rule. On the real side of the economy, the standard qualitative effects are observed. A monetary tightening leads to a drop in GDP, consumption, and investment by 0.17, 0.08, and 0.63 percent relative to the steady state. Employment in both goods production and the banking falls significantly (see figure 6).

At this point, the popular non-backward-looking character of firms' optimal price setting is somewhat unfortunate. Since the current period's inflation rate  $\pi_t$  is not predetermined<sup>23</sup>, part of the monetary policy shock is absorbed by an instantaneous deceleration of inflation. Yet, I would like to emphasise that the impact on the *real* interest rate is the same, whether it originates from an increase in the nominal interest rate or from reduced inflation.

Obviously, retail rates increase by far less than the policy rate. A slowdown in economic activity lowers the demand for financial intermediation. Although liquidity services  $d$  fade by 0.08 percent in line with consumption, the severe contraction in the supply of high-powered money raises the costs of deposit provision. As a consequence, banks demand a higher *IMP*, passing only 13% of the change in the policy rate on to the deposit rate. At the same time, the demand for loans  $l$  falls by 0.95 percent relative to its steady-state. The loan rate differential decreases thus by up to 16.5 basis points.

The fluctuations in both retail rates and the corresponding premia are demand driven. For this reason, the *EFP* does not display the standard countercyclical behaviour (see Bernanke et al. (1999)), according to which it should fall in a boom and rise in a bust. As mentioned earlier, this is due to the fact that the “financial accelerator” is largely switched off in this model.

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<sup>23</sup>Note that even if  $\pi_t$ , the change in the price level between period  $t - 1$  and  $t$  is not predetermined, the previous period's price level  $P_{t-1}$  clearly is. Accordingly, the rate of inflation becomes a jump variable through changes in the current period price level.

### Deposit-in-Advance shock

The largest part of an increase in the minimum deposit requirement per unit of consumption is compensated by an immediate waiving of household consumption. In response to a rise in  $\alpha$ , the latter falls by 0.51 percent relative to its stationary value. Adjustment of deposits is costly and satisfies the tightened constraint with a lag, only. The drop in consumption slows down inflation, as illustrated in figure 7. A delayed increase in investment by barely 0.08 percent is not enough to prevent an instantaneous drop in GDP by 38 basis points. As a consequence, employment falls by 0.6 percent.

The central bank reacts to the slowdown of inflation by easing monetary policy. While the interest rate on loans follows  $r$  rather closely, the deposit rate falls by somewhat less. Demand for loans drops by 0.53 percent. Therefore, banks require less monitoring. These redundancies in the banking sector are prolonged by the steady increase in firms' productive capital stock and thus collateral.

Similar to the case of a positive technology shock, the spread between  $r^d$  and the policy rate does not rise in response to a tightening of the DIA constraint. With high-powered money reserves increasing by 1.8 percent in the first and another 0.7 percent in the second and third quarter, commercial banks can even provide deposit accounts at a slightly reduced cost. They demand thus a lower *IMP*.

### Inside-Money-Premium shock

The two remaining exogenous disturbances originate directly from the banking sector. They are expected to have minor influence on the real economy. The impulse responses of selected variables to an increase in  $\omega$ , which makes the provision of deposits more costly, are depicted in figure 8. Commercial banks react by accumulating larger reserves of high-powered money. This limits the rise in costs and has a moderating effect on the *IMP*. Accordingly, the interest rate on deposit accounts decreases by a mere 0.009 basis points relative to the steady state.

Nevertheless, any fall in  $r^d$  corresponds to an increase in the liquidity cost of consumption. Households thus reduce their consumption expenditure and deposit holdings, though by an insignificant amount. The lower level of consumption implies a higher marginal utility and, from the loglinearised equation (B.2), either a fall in the real wage or an increase in employment. While  $w$  remains broadly constant, both  $n$  and  $s$  rise

subtly. As a consequence, the simulation predicts a slight expansive effect on output and inflation, while firms invest less. Following the Taylor rule, the monetary authority counteracts any inflation by raising the policy rate. Note that all deviations in the impulse responses of real variables are of the order  $10^{-4}$  or minor.

### **External-Finance-Premium shock**

I finally expose the model to a positive technology shock in bank monitoring of size  $\sigma_\chi$ . As expected, increased efficiency in loan production makes part of the financial sector employees redundant –  $s$  falls by 0.8 percent. Still, credit contracts can be provided at a lower cost. This is passed on to clients as a reduction in the *EFP* by 0.26 basis points and a comparable drop in the quarterly loan interest rate  $r^l$ , illustrated in figure 9.

Goods producers benefit from this cheaper source of funds. They borrow additional working capital to expand employment and investment by up to 0.26 and 0.5 basis points, respectively. It is due to the increased labour demand that firm output grows by 0.19 basis points during the first year. The faster accumulation of capital affects production capacity with a lag, only.

With regard to the lower borrowing costs of firms, a rise in the productivity of monitoring is comparable to a positive supply shock. It generates a small immediate slowdown in inflation. The monetary authority follows its Taylor rule and lowers the policy rate by a maximum of  $2 \cdot 10^{-4}$  percentage points, after four quarters. This suffices to curb the real interest rate and ensure convergence. Only about half of the change in the policy rate is passed on to the deposit retail rate, which causes a reduction in the *IMP*.

The quantitative analysis of impulse responses suggests that the contribution of disturbances emerging from financial intermediation to the business cycle is of second order importance. The present model contains two such shocks – one impeding the provision of deposit accounts and one varying the efficiency in loan production. By influencing the spreads between the risk-free policy rate  $r$  and the interest rate on bank deposits and loans, respectively, these shocks have an impact on agents' optimal decision making. Both affect output, consumption, investment, and the like through a *retail rate channel*.

## 6.2.2 Monetary Policy and Financial Intermediation

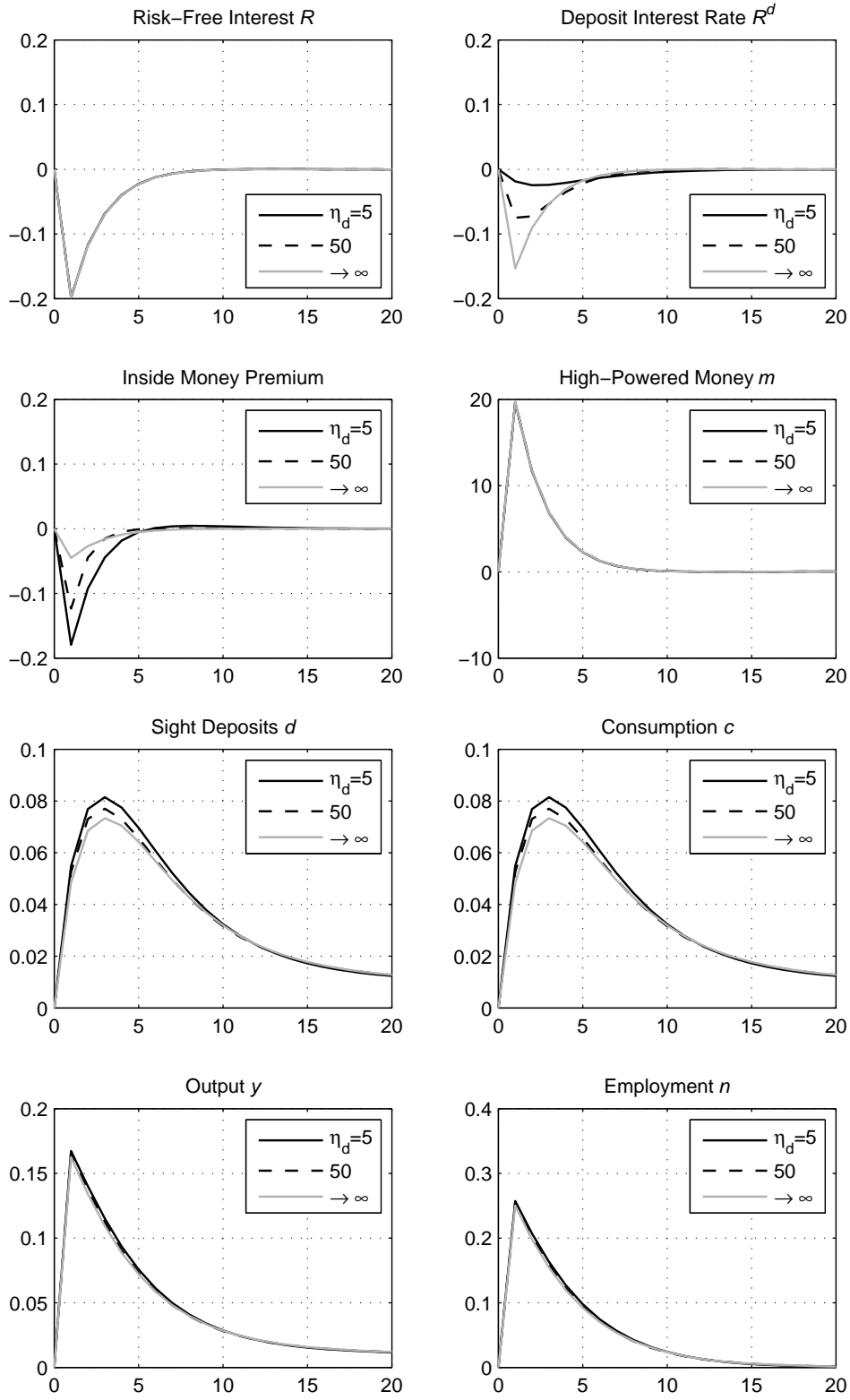
This paper's key question is whether and to what extent the short-run pass-through from changes in the policy rate to the real economy depends on the degree of competition in the banking sector. In the light of recent central bank behaviour, the subsequent sensitivity analyses focus on the impulse responses of a selection of variables to an expansive monetary policy shock.

### The Impact of Competition in the Deposit Market

The novelty with respect to the underlying model by Goodfriend and McCallum (2007) is the fact that commercial banks enjoy a quantifiable interest rate setting power.

In the following analysis, I set the interest elasticity of demand for deposit contracts provided by a certain bank,  $\eta_d$ , to 5, 50, and  $1 \cdot 10^{12}$ . These values characterise the benchmark case, a situation with reduced market power, and perfect competition in the market for deposits. All three are solved numerically, i. e. simulated for 2000 periods, in order to extract so-called policy and transmission functions as well as first and second order moments of the model's endogenous variables. A selection of the impulse responses for the first 20 periods succeeding an expansionary monetary policy shock is presented in figure 3.

As expected, the stock of high-powered money soars directly after the drop in the policy rate. However, the extent of this increase is insensitive to the parameter under consideration. I thus focus on the impulse responses of  $r^d$  and the corresponding interest differential. Even under perfect competition, the *IMP* displays some variation, which is entirely due to fluctuations in the endogenous costs of deposit provision  $\frac{\omega d_t}{m_t}$ . With  $\eta_d=50$ , demand for bank deposits is still elastic enough to trace the previous case closely. If, however, the market for deposits displays a monopolistically competitive structure, where agents profit from considerable interest rate setting power, the *IMP* drops by 18 basis points in response to the expansive monetary shock. Private banks find it optimal to adjust the deposit rate with a lag and by merely one quarter of the percentage point revision we observe in a perfectly competitive market.



**Figure 3:** Impulse responses to a monetary policy innovation for  $\eta_d = 5, 50$ , and  $1 \cdot 10^{12}$

Nevertheless, the effect on consumption and deposits is remarkable only in the first two years following the change in the policy rate. The percentage deviation from steady state in the benchmark scenario exceeds that in the perfect competition case by up to ten percent. Incomplete pass-through from monetary policy to the bank interest rate leads to a reduction in the opportunity cost of deposit-secured consumption – the *IMP*. It is thus optimal for the representative household to increase consumption by more, *ceteris paribus*, the higher the market power of banks.<sup>24</sup> The same is observable in the reactions of GDP and employment to an innovation in the policy rate. Yet, the effect appears marginal, even for a low degree of interest-rate elasticity.

Optimal behaviour of commercial banks implies use of their interest rate setting power. While the adjustment of consumption is sensitive to  $\eta_d$ , the difference in output and employment is below one basis point. We can state that limited competition in the market for deposits marginally amplifies the expansion of real economic activity after an unforeseen drop in the monetary policy rate.

### **The Degree of Loan Market Competition**

The final sensitivity analysis examines the role of monopolistic competition in the market for loans. Again, I choose three values for the parameter  $\eta_l$  that characterise the benchmark, an increased, and – at least approximately – infinitely high substitutability between the credit contracts supplied by different banks. I therefore pick values of 7, 50, and  $1 \cdot 10^{12}$ .

Surprisingly, the structural composition of the loan market has a much stronger influence on the economy’s real side than that of the market for deposits. After an unanticipated monetary expansion, commercial banks naturally lower their loan rate. Yet, how closely they follow the policy rate, depends on two aspects: On the one hand, a rising real wage rate and higher need for monitoring effort – due to the increased loan demand – raise the cost of loan production and the *EFP*. On the other hand, monopolistically competitive banks consider market share effects and adjustment costs in their interest rate setting. They accept a temporary surge in the *EFP* relative to the perfect competition scenario, the extent of which is negatively correlated with the size of  $\eta_l$ . For an interest elasticity

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<sup>24</sup>A weak point of the model is that it does not allow for asymmetric pass-through of changes in market rates. On the other hand, shielding depositors symmetrically from both upward and downward interest fluctuations would suit an implicit risk-sharing motivation (Berger and Udell (1992)).

set to the benchmark value of 7, the model predicts a maximum reduction in  $r^l$  by 3.9 basis points, opposed by nearly 19 basis points when  $\eta_l \rightarrow \infty$ . This corresponds to a percentage deviation from steady state five times as large or a transmission of only 20% in the short run. Even when market power is reduced, profit maximisation still invites banks to smooth the loan interest rate in response to a drop in  $r$ , allowing for a transitory increase in the *EFP* by more than 10 basis points.

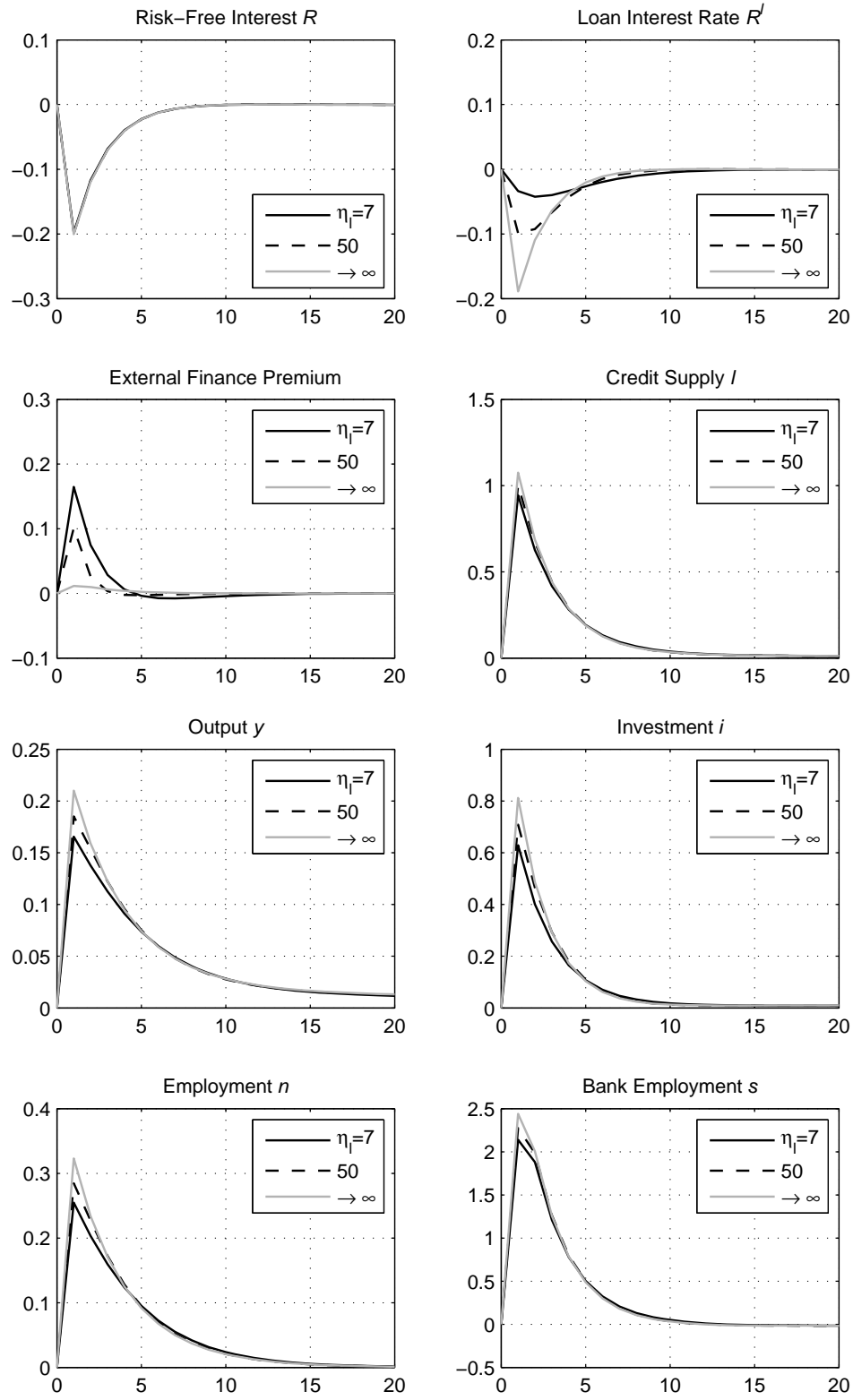
In accordance with the empirical literature, the model predicts that monopolistic competition among commercial banks attenuates the pass-through from market to retail interest rates. I already remarked that the role of market power in the loan sector dwarfs the effect of competition among deposit providers. In absolute terms, the instantaneous responses of output and employment for  $\eta_l = 7$  and  $\eta_l \rightarrow \infty$  differ by approximately 4.5 and 7 basis points; that of loans more than 12 basis points. In line with the empirical evidence, investment into productive capital displays the highest interest sensitivity among the real variables. On impact, its deviations from the steady state reach from +0.63 to +0.81 percent – a difference of almost 30 percent.

The preceding sensitivity analysis suggests that monopolistic competition in the loan market might be a significant bottleneck for monetary policy. In this respect, the model agrees with the empirical evidence (see e. g. van Leuvensteijn et al. (2008) who exclusively consider loan market competition, and de Bondt (2005)). The pass-through from policy and thus market interest rates to bank retail rates is weaker in less competitive markets. Banks as interest-rate makers cushion thus the response of real variables.

This result has an important implication in the light of the currently observed credit crunch. Although central banks worldwide pursued an expansive monetary policy of unprecedented determination<sup>25</sup>, private banks failed to fully pass this reduction in the central bank interest rate on to borrowers. As a consequence, the shortage in loan supply, a major threat especially to small and medium-sized firms which are unable to refinance themselves through the stock market, persists to this day. While it is not certain, to what extent the assessed imperfect pass-through reflects the risk considerations of intermediaries, delayed and incomplete adjustment of bank rates to the policy rate strongly indicates the existence of interest rate setting power.

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<sup>25</sup>Between October 2008 and May 2009, the European Central Bank has reduced the interest rate on main refinancing operations by 325 basis points from a level of 4.25% to currently 1.00%.



**Figure 4:** Impulse responses to a monetary policy shock for  $\eta_l = 7, 50$ , and  $1 \cdot 10^{12}$



## 7 Conclusion

In the model presented here, private agents rely on two types of financial services, namely deposits and loans provided by commercial banks. Moreover, the services of different banks substitute imperfectly against each other. The spreads between the risk-free refinancing rate and bank retail rates – the so-called *inside money* and *external finance premium* – are thus determined by standard cost arguments of financial intermediation as well as by the degree of monopolistic competition in the respective banking sector. In the long-run steady state, when adjustment costs do not play a role, the real effects of market imperfections are negligible.

The results of the dynamic simulation suggest that innovations inherent to the banking sector are relatively unimportant in comparison with the three common shocks. Yet, my framework is not flexible enough to simulate a severe financial crisis like the present credit crunch, which might change theoretical predictions. This seems an interesting direction for further model extensions.

The concluding sensitivity analysis compares the impulse responses of selected variables to an unforeseen monetary expansion. It evaluates the importance of competition in bank product markets for the pass-through of monetary policy in the short run. Imperfect competition among the providers of deposits acts as a financial accelerator, in this model. By contrast, credit contract heterogeneity curbs the response of the loan rate to changes in market interest rates and absorbs thus part of the monetary policy shock.

While the degree of competition in the deposit market has merely marginal influence, the interest sensitivity of loan demand not only dominates the former, but is clearly quantitatively important for the behaviour of the economy over the business cycle.

## Appendix A. The Symmetric Equilibrium

The symmetric equilibrium is an infinite time series of the 23 endogenous variables  $y, c, i, k, n, s, w, g, g^f, r, r^d, r^l, m, d, l, \pi, g^{cb}, b, \lambda, \xi, \Xi, \lambda^1$ , and  $\lambda^2$  given the exogenous shock processes  $\alpha, \theta, \omega, \chi$ , and  $r$ , that solves the following system of 23 equations. (A.1) to (A.12) replicate the household and firm FOCs as well as the corresponding constraints:

$$\frac{1}{c_t} = \lambda_t + \xi_t \alpha_t \quad (\text{A.1})$$

$$\phi = \lambda_t w_t (1 - n_t - s_t) \quad (\text{A.2})$$

$$\lambda_t = \beta E_t \lambda_{t+1} \frac{1 + r_t}{\pi_{t+1}} \quad (\text{A.3})$$

$$\begin{aligned} \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + r_t^d}{\pi_{t+1}} + \frac{\xi_t}{\lambda_t} \\ = 1 + \phi_d \left( \frac{d_t}{d_{t-1}} - 1 \right) + \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[ \phi_d \left( \frac{d_{t+1}^2}{d_t^2} - \frac{d_{t+1}}{d_t} \right) - \frac{\phi_d}{2} \left( \frac{d_{t+1}}{d_t} - 1 \right)^2 \right] \end{aligned} \quad (\text{A.4})$$

$$c_t + d_t + \frac{\phi_d}{2} \left( \frac{d_t}{d_{t-1}} - 1 \right)^2 d_{t-1} = w_t (n_t + s_t) + \frac{d_{t-1} (1 + r_{t-1}^d)}{\pi_t} + g_t + g_t^f + g_t^{cb} \quad (\text{A.5})$$

$$\alpha_t c_t = d_t \quad (\text{A.6})$$

$$\beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}} (1 + r_t^l) w_t n_t = (1 - \gamma) \Xi_t y_t \quad (\text{A.7})$$

$$(1 - \mu) + \mu \frac{\Xi_t}{\lambda_t} + \mu \frac{\phi_p}{2} \left( \frac{\pi_t}{\pi} - 1 \right)^2 = \phi_p \left( \frac{\pi_{t+1}^2}{\pi^2} - \frac{\pi_{t+1}}{\pi} \right) \frac{y_{t+1}}{y_t} \quad (\text{A.8})$$

$$\begin{aligned} \beta^2 E_t \frac{\lambda_{t+2}}{\pi_{t+2}} (1 - \delta) (1 + r_{t+1}^l) - \beta E_t \frac{\lambda_{t+1}}{\pi_{t+1}} (1 + r_t^l) + \beta \gamma E_t \Xi_{t+1} \frac{y_{t+1}}{k_t} \\ = \lambda_t \phi_k \left( \frac{k_t}{k_{t-1}} - 1 \right) - \beta E_t \lambda_{t+1} \phi_k \left( \frac{k_{t+1}^2}{k_t^2} - \frac{k_{t+1}}{k_t} \right) + \beta E_t \lambda_{t+1} \frac{\phi_k}{2} \left( \frac{k_{t+1}}{k_t} - 1 \right)^2 \end{aligned} \quad (\text{A.9})$$

$$k_t = (1 - \delta) k_{t-1} + i_t \quad (\text{A.10})$$

$$y_t = e^{\theta_t} k_{t-1}^\gamma n_t^{1-\gamma} \quad (\text{A.11})$$

$$g_t = y_t - \frac{(1 + r_{t-1}^l) (w_{t-1} n_{t-1} + i_{t-1})}{\pi_t} - \frac{\phi_p}{2} \left( \frac{\pi_t}{\pi} - 1 \right)^2 - \frac{\phi_k}{2} \left( \frac{k_t}{k_{t-1}} - 1 \right)^2 k_{t-1} \quad (\text{A.12})$$

(A.13)–(A.15) characterise the behaviour of the monetary authority. (A.16) is the profit function of a financial intermediary, while (A.17) and (A.18) describe the equilibrium loan demand and supply. (A.19)–(A.21) are the symmetric *IMP*, *EFP*, and money demand, respectively. Finally, (A.22) and (A.23) represent the optimal interest rate setting of banks in a scenario with monopolistic competition and adjustment costs.

$$m_t = b_t \quad (\text{A.13})$$

$$r_t = (1 - \rho)(\beta^{-1} - 1 + \varphi_\pi(\pi_t - 1)) + \rho r_{t-1} + \epsilon_t^R \quad (\text{A.14})$$

$$g_t^{cb} = m_t + \frac{b_{t-1}(1 + r_{t-1})}{\pi_t} - b_t - \frac{m_{t-1}}{\pi_t} \quad (\text{A.15})$$

$$\begin{aligned} g_t^f = & d_t + b_t + \frac{m_{t-1}}{\pi_t} + \frac{l_{t-1}(1 + r_{t-1}^l)}{\pi_t} - \frac{d_{t-1}(1 + r_{t-1}^d)}{\pi_t} - \frac{b_{t-1}(1 + r_{t-1})}{\pi_t} \\ & - l_t - m_t - w_t s_t - \frac{\omega_t d_t}{m_t} - \frac{\phi_{rd}}{2} \left( \frac{r_t^d}{r_{t-1}^d} - 1 \right)^2 d_t - \frac{\phi_{rl}}{2} \left( \frac{r_t^l}{r_{t-1}^l} - 1 \right)^2 l_t \end{aligned} \quad (\text{A.16})$$

$$l_t = w_t n_t + i_t \quad (\text{A.17})$$

$$l_t = F(g_t + qk_t)^\sigma (e^{X_t} s_t)^{1-\sigma} \quad (\text{A.18})$$

$$E_t \frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} (r_t - r_t^d) = \frac{\omega_t}{m_t} - \frac{\lambda_t^d}{\lambda_t} + \frac{\phi_{rd}}{2} \left( \frac{r_t^d}{r_{t-1}^d} - 1 \right)^2 \quad (\text{A.19})$$

$$E_t \frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} (r_t^l - r_t) = \frac{w_t s_t}{(1 - \sigma) l_t} - \frac{\lambda_t^l}{\lambda_t} + \frac{\phi_{rl}}{2} \left( \frac{r_t^l}{r_{t-1}^l} - 1 \right)^2 \quad (\text{A.20})$$

$$E_t \frac{\beta}{\pi_{t+1}} \frac{\lambda_{t+1}}{\lambda_t} (r_t - 1) = \frac{\omega_t d_t}{m_t^2} \quad (\text{A.21})$$

$$\begin{aligned} \eta_d - \beta(1 + \eta_d) E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{r_t^d}{\pi_{t+1}} - \eta_d E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{\beta}{\pi_{t+1}} - \eta_d \frac{\omega_t}{m_t} - \eta_d \frac{\phi_{rd}}{2} \left( \frac{r_t^d}{r_{t-1}^d} - 1 \right)^2 \\ = \phi_{rd} \left( \frac{r_t^{d^2}}{r_{t-1}^{d^2}} - \frac{r_t^d}{r_{t-1}^d} \right) - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \phi_{rd} \left( \frac{r_{t+1}^{d^2}}{r_t^{d^2}} - \frac{r_{t+1}^d}{r_t^d} \right) \frac{d_{t+1}}{d_t} + \eta_d \frac{\lambda_t^d}{\lambda_t} \end{aligned} \quad (\text{A.22})$$

$$\begin{aligned} \eta_l + \beta(1 - \eta_l) E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{r_t^l}{\pi_{t+1}} - \eta_l E_t \frac{\lambda_{t+1}}{\lambda_t} \frac{\beta}{\pi_{t+1}} + \eta_l \frac{\phi_{rl}}{2} \left( \frac{r_t^l}{r_{t-1}^l} - 1 \right)^2 \\ = \phi_{rl} \left( \frac{r_t^{l^2}}{r_{t-1}^{l^2}} - \frac{r_t^l}{r_{t-1}^l} \right) - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \phi_{rl} \left( \frac{r_{t+1}^{l^2}}{r_t^{l^2}} - \frac{r_{t+1}^l}{r_t^l} \right) \frac{l_{t+1}}{l_t} - \eta_l \frac{\lambda_t^l}{\lambda_t} \end{aligned} \quad (\text{A.23})$$

## Appendix B. The Model in Loglinear Form

Below,  $\hat{x}_t$  stands for the percentage deviation of variable  $x$  from its stationary equilibrium in period  $t$ . Note that the denotations  $\hat{r}_t$ ,  $\hat{r}_t^d$ , and  $\hat{r}_t^l$  have a slightly different meaning: The interest rates on risk-free bonds, deposits, and loans enter the loglinear system in terms of absolute deviation from steady states, i. e. in percentage points.

The order and the meaning of equations (B.1)–(B.12) corresponds to that in Appendix A.

$$0 = \left(\frac{1}{c}\right) \hat{c}_t + \lambda \hat{\lambda}_t + \xi \alpha \hat{\xi}_t + \alpha \xi \hat{\alpha}_t \quad (\text{B.1})$$

$$0 = \hat{w}_t + \hat{\lambda}_t - \frac{1}{1-n-s} (n \hat{n}_t + s \hat{s}_t) \quad (\text{B.2})$$

$$0 = \beta \hat{r}_t - E_t \hat{\pi}_{t+1} + E_t \hat{\lambda}_{t+1} - \hat{\lambda} \quad (\text{B.3})$$

$$0 = \beta \phi_d E_t \hat{d}_{t+1} - (1 + \beta) \phi_d \hat{d}_t + \phi_d \hat{d}_{t-1} + \beta \frac{1}{\pi} \hat{r}_t^d + \beta \frac{1+r^d}{\pi} E_t [\hat{\lambda}_{t+1} - \hat{\pi}_{t+1}] - \hat{\lambda}_t + \frac{\xi}{\lambda} \hat{\xi}_t \quad (\text{B.4})$$

$$0 = c \hat{c}_t + d \hat{d}_t - w n (\hat{w}_t + \hat{n}_t) - w s (\hat{w}_t + \hat{s}_t) - \frac{d}{\pi} \hat{r}_{t-1}^d - \frac{(1+r^d)d}{\pi} (\hat{d}_{t-1} - \hat{\pi}_t) - g \hat{g}_t - g^f \hat{g}_t^f - g^{cb} \hat{g}_t^{cb} \quad (\text{B.5})$$

$$0 = \hat{d}_t - \hat{c}_t - \hat{\alpha}_t \quad (\text{B.6})$$

$$0 = \hat{r}_t^l + E_t (\hat{\lambda}_{t+1} - \hat{\pi}_{t+1}) + \hat{w}_t + \hat{n}_t - \hat{\Xi}_t - \hat{y}_t \quad (\text{B.7})$$

$$0 = (1 - \mu) \hat{\lambda}_t + (\mu - 1) \hat{\Xi}_t - \phi_p \hat{\pi}_t + \beta \phi_p E_t \hat{\pi}_{t+1} \quad (\text{B.8})$$

$$0 = \beta \phi_k E_t \hat{k}_{t+1} - \left[ (1 + \beta) \phi_k + \beta \gamma \frac{\Xi}{\lambda} \frac{y}{k} \right] \hat{k}_t + \phi_k \hat{k}_{t-1} + \beta^2 (1 - \delta) \frac{1+r^l}{\pi} E_t (\hat{\lambda}_{t+2} - \hat{\pi}_{t+2}) + \beta \gamma \frac{\Xi}{\lambda} \frac{y}{k} E_t \hat{y}_{t+1} - \beta \frac{1+r^l}{\pi} E_t (\hat{\lambda}_{t+1} - \hat{\pi}_{t+1}) + \beta \gamma \frac{\Xi}{\lambda} \frac{y}{k} E_t \hat{\Xi}_{t+1} + \frac{\beta^2}{\pi} (1 - \delta) \hat{r}_{t+1}^l - \frac{\beta}{\pi} \hat{r}_t^l \quad (\text{B.9})$$

$$0 = \hat{k}_t - (1 - \delta) \hat{k}_{t-1} - \delta \hat{i}_t \quad (\text{B.10})$$

$$0 = \gamma \hat{k}_{t-1} + (1 - \gamma) \hat{n}_t - \hat{y}_t + \hat{\theta}_t \quad (\text{B.11})$$

$$0 = g \hat{g}_t - y \hat{y}_t + \frac{w n + i}{\pi} \hat{r}_{t-1}^l + \frac{1+r^l}{\pi} [w n (\hat{w}_{t-1} + \hat{n}_{t-1}) + i \hat{i}_{t-1} + (w n + i) \pi \hat{\pi}_t] \quad (\text{B.12})$$

(B.13)–(B.15) capture central bank behaviour in loglinear terms, now. (B.19) and (B.20) are the *IMP* and *EFP* equilibrium conditions expressed in percentage deviations from steady state, while (B.22) and (B.23) are the loglinearised FOCs w. r. t. the deposit and loan interest rate, respectively. Obviously, imperfect competition among banks yields a kind of hybrid Phillips curve in retail interest rates, when adjusting the latter is costly.

$$0 = \hat{m}_t - \hat{b}_t \quad (\text{B.13})$$

$$0 = \hat{r}_t - \rho \hat{r}_{t-1} - (1 - \rho) \varphi_\pi \pi \hat{\pi}_t - \epsilon_t^r \quad (\text{B.14})$$

$$0 = g^{cb} \hat{g}_t^{cb} - m \hat{m}_t - \frac{b}{\pi} \hat{r}_{t-1} - \frac{b(1+r)}{\pi} (\hat{b}_{t-1} - \hat{\pi}_t) + b \hat{b}_t + \frac{m}{\pi} (\hat{m}_{t-1} - \hat{\pi}_t) \quad (\text{B.15})$$

$$\begin{aligned} 0 = & g^f \hat{g}_t^f + l \hat{l}_t - d \hat{d}_t - b \hat{b}_t - \frac{m}{\pi} (\hat{m}_{t-1} - \hat{\pi}_t) - \frac{l(1+r^l)}{\pi} (\hat{l}_{t-1} - \hat{\pi}_t) - \frac{l}{\pi} \hat{r}_{t-1}^l + \frac{d(1+r^d)}{\pi} (\hat{d}_{t-1} - \hat{\pi}_t) \\ & + \frac{d}{\pi} \hat{r}_{t-1}^d + \frac{b(1+r)}{\pi} (\hat{b}_{t-1} - \hat{\pi}_t) + \frac{b}{\pi} \hat{r}_{t-1} + m \hat{m}_t + ws(\hat{w}_t + \hat{s}_t) + \frac{\omega d}{m} (\hat{\omega}_t + \hat{d}_t - \hat{m}_t) \end{aligned} \quad (\text{B.16})$$

$$0 = l \hat{l}_t - wn(\hat{w}_t + \hat{n}_t) - \hat{v}_t \quad (\text{B.17})$$

$$0 = \hat{l}_t - \frac{\sigma q k}{g + q k} \hat{k}_t - (1 - \sigma) \hat{s}_t - \frac{\sigma g}{g + q k} \hat{g}_t - (1 - \sigma) \hat{\chi}_t \quad (\text{B.18})$$

$$0 = \frac{\beta}{\pi} (\hat{r}_t - \hat{r}_t^d) - \frac{\beta}{\pi} (r - r^d) E_t(\hat{\pi}_{t+1} - \hat{\lambda}_{t+1} + \hat{\lambda}_t) - \frac{\omega}{m} (\hat{\omega}_t - \hat{m}_t) + \frac{\lambda^d}{\lambda} (\hat{\lambda}_t^d - \hat{\lambda}_t) \quad (\text{B.19})$$

$$0 = \frac{\beta}{\pi} (\hat{r}_t^l - \hat{r}_t) - \frac{\beta}{\pi} (r^l - r) E_t(\hat{\pi}_{t+1} - \hat{\lambda}_{t+1} + \hat{\lambda}_t) - \frac{ws}{(1 - \sigma)l} (\hat{w}_t + \hat{s}_t - \hat{l}_t) + \frac{\lambda^l}{\lambda} (\hat{\lambda}_t^l - \hat{\lambda}_t) \quad (\text{B.20})$$

$$0 = \frac{\beta}{\pi} \hat{r}_t - \frac{\beta r}{\pi} E_t(\hat{\pi}_{t+1} - \hat{\lambda}_{t+1} + \hat{\lambda}_t) - \frac{\omega d}{m^2} (\hat{\omega}_t + \hat{d}_t - 2\hat{m}_t) \quad (\text{B.21})$$

$$\begin{aligned} 0 = & \beta \frac{\phi_{r^d}}{r^d} E_t \hat{r}_{t+1}^d - \left[ (1 + \beta) \frac{\phi_{r^d}}{r^d} + (1 + \eta_d) \frac{\beta}{\pi} \right] \hat{r}_t^d + \frac{\phi_{r^d}}{r^d} \hat{r}_{t-1}^d + \eta_d \frac{\omega}{m} (\hat{m}_t - \hat{\omega}_t) \\ & + \frac{\beta}{\pi} [(1 + \eta_d) r^d + \eta_d] E_t(\hat{\pi}_{t+1} - \hat{\lambda}_{t+1} + \hat{\lambda}_t) - \eta_d \frac{\lambda^d}{\lambda} (\hat{\lambda}_t^d - \hat{\lambda}_t) \end{aligned} \quad (\text{B.22})$$

$$\begin{aligned} 0 = & \beta \frac{\phi_{r^l}}{r^l} E_t \hat{r}_{t+1}^l - \left[ (1 + \beta) \frac{\phi_{r^l}}{r^l} - (1 - \eta_l) \frac{\beta}{\pi} \right] \hat{r}_t^l + \frac{\phi_{r^l}}{r^l} \hat{r}_{t-1}^l \\ & - \frac{\beta}{\pi} [(1 - \eta_l) r^l - \eta_l] E_t(\hat{\pi}_{t+1} - \hat{\lambda}_{t+1} + \hat{\lambda}_t) + \eta_l \frac{\lambda^l}{\lambda} (\hat{\lambda}_t^l - \hat{\lambda}_t) \end{aligned} \quad (\text{B.23})$$

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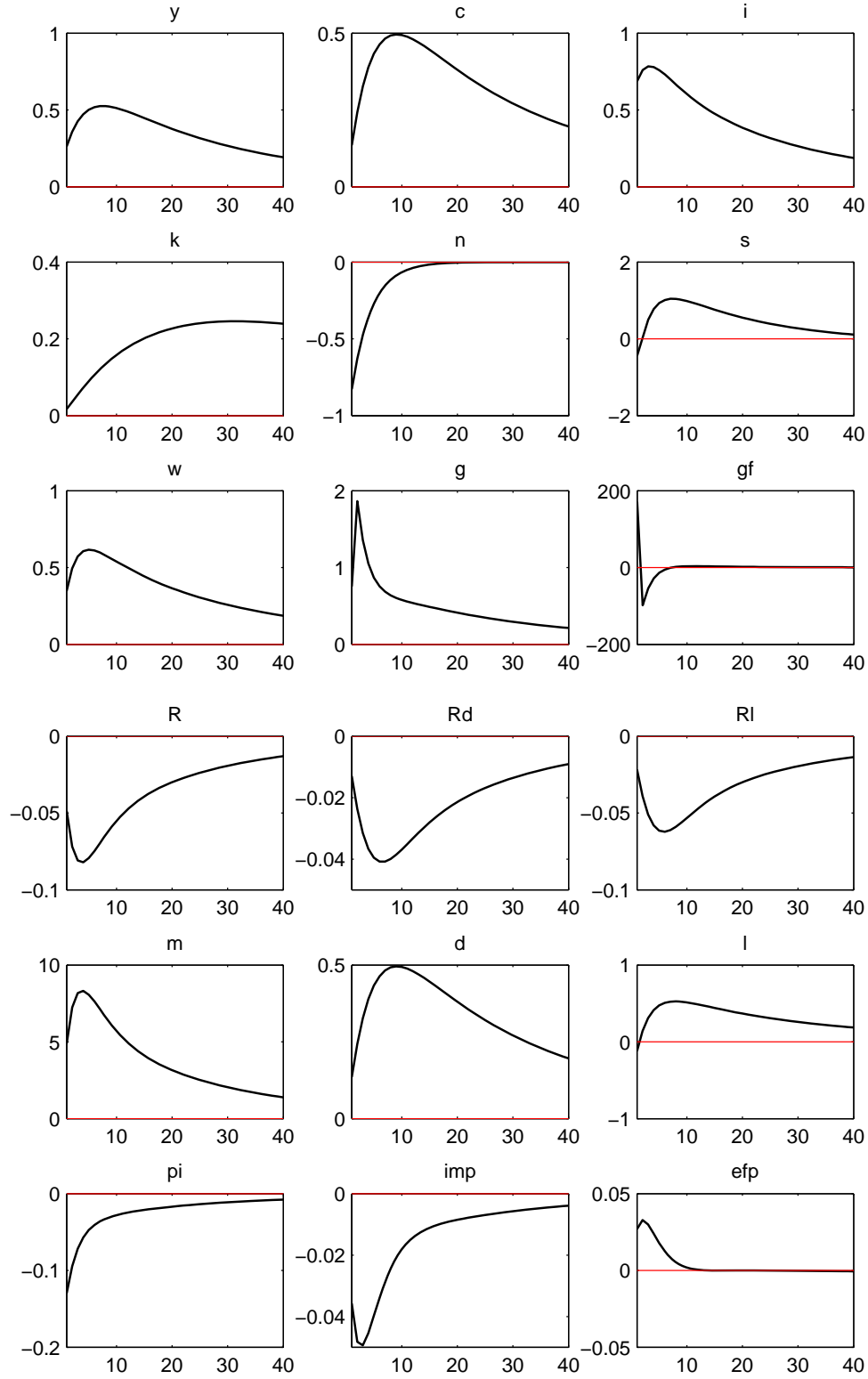


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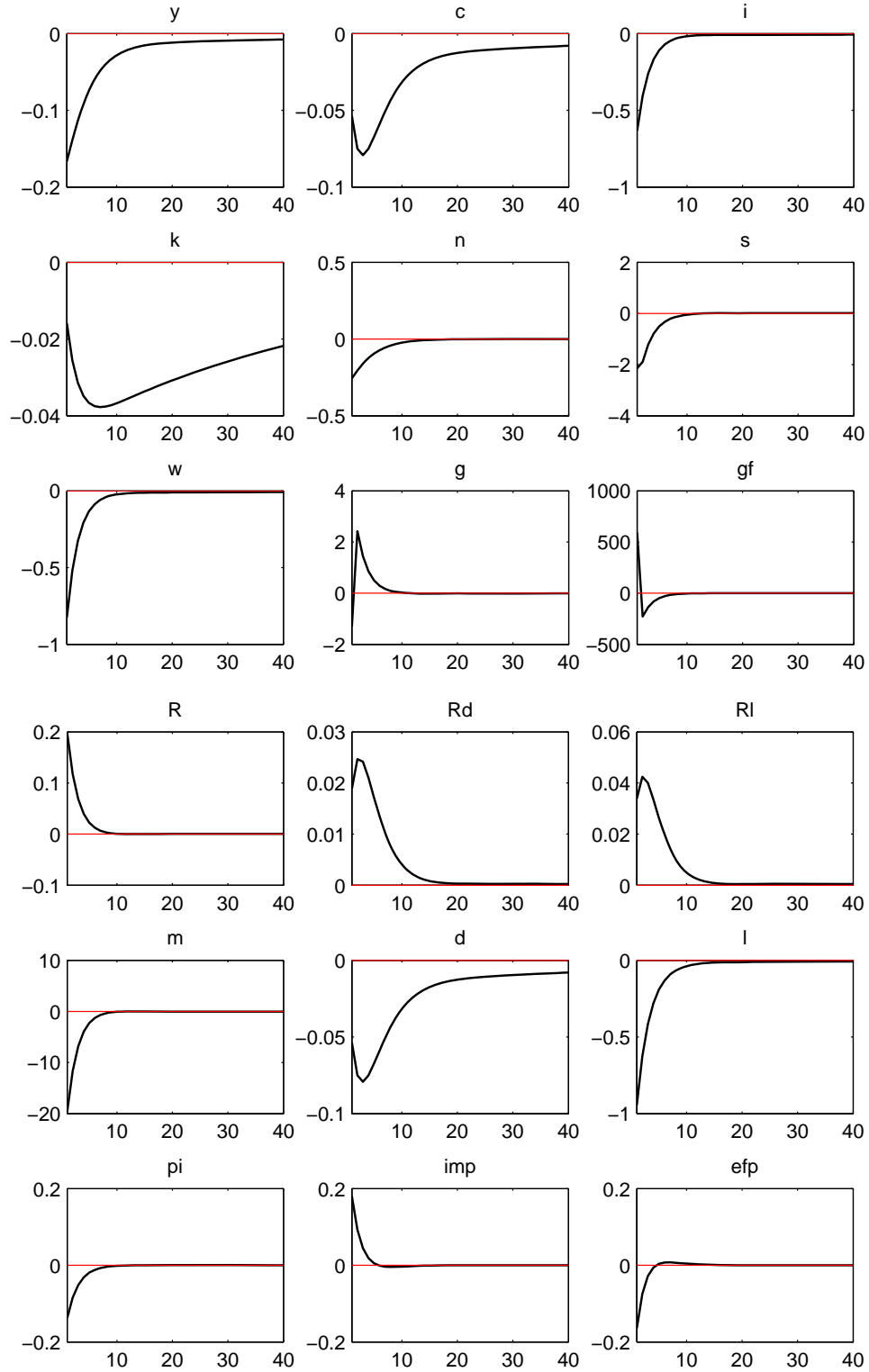
## Completive Tables and Figures

Parameter Values ( <i>benchmark calibration</i> )			
Coefficient	Value	Coefficient	Value
$\alpha$	0.8	$\phi_d$	30
$\beta$	0.995	$\phi_{r^d}$	0.25
$\gamma$	0.35	$\phi_{r^l}$	1
$\delta$	0.025	$\rho$	0.75
$\phi$	1.43	$\phi_\pi$	1.5
$\omega$	0.001	$\sigma_r$	0.25
$\sigma$	0.6	$\rho_\theta$	0.95
$F$	6	$\sigma_\theta$	0.80
$q$	0.20	$\rho_\alpha$	0.88
$\mu$	6	$\sigma_\alpha$	0.60
$\eta_d$	5	$\rho_\omega$	0.90
$\eta_l$	7	$\sigma_\omega$	0.18
$\phi_k$	35	$\rho_\chi$	0.90
$\phi_p$	100	$\sigma_\chi$	0.80

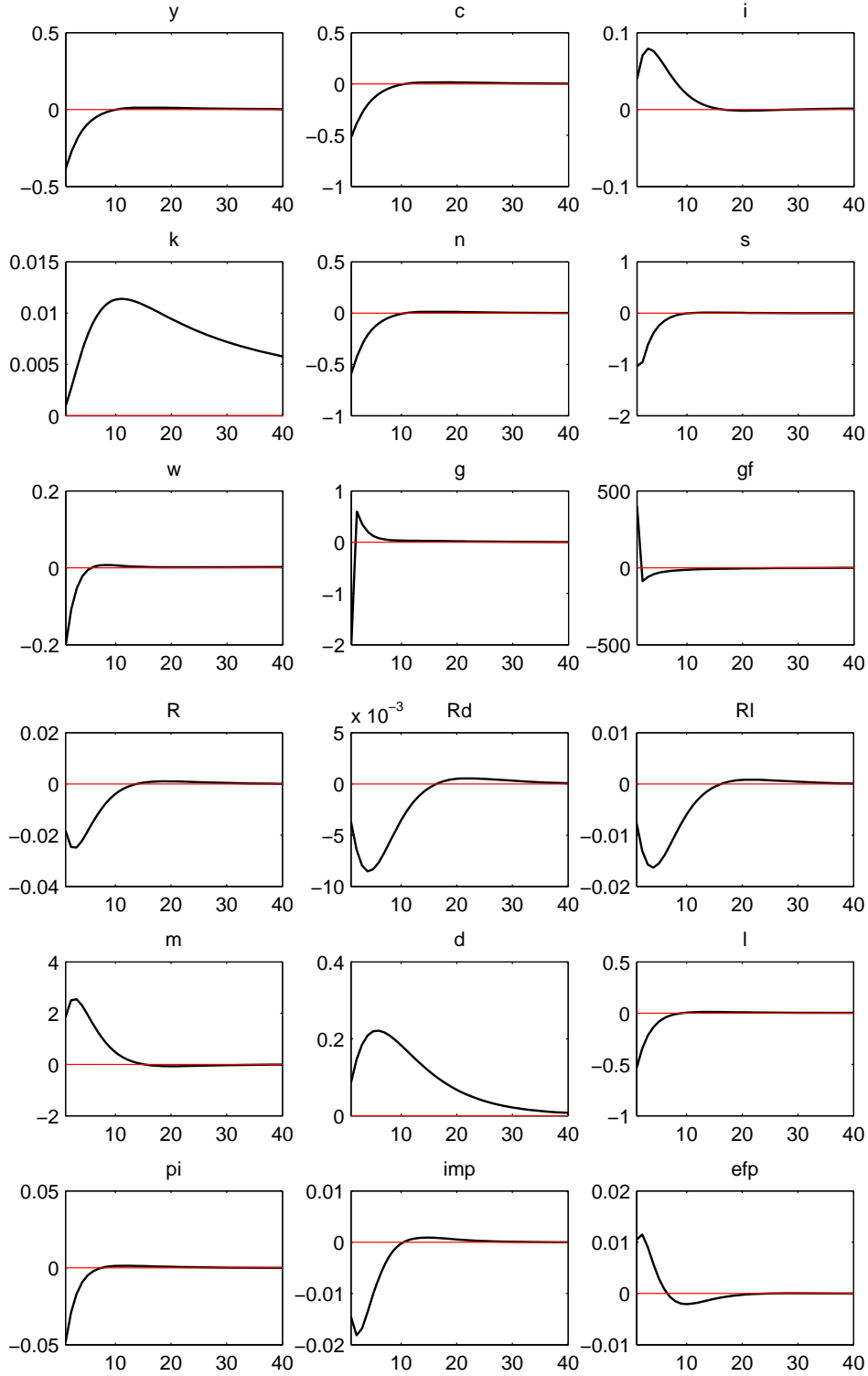
**Table 2:** Benchmark calibration of all model parameters relevant for the economy's steady state and dynamic behaviour



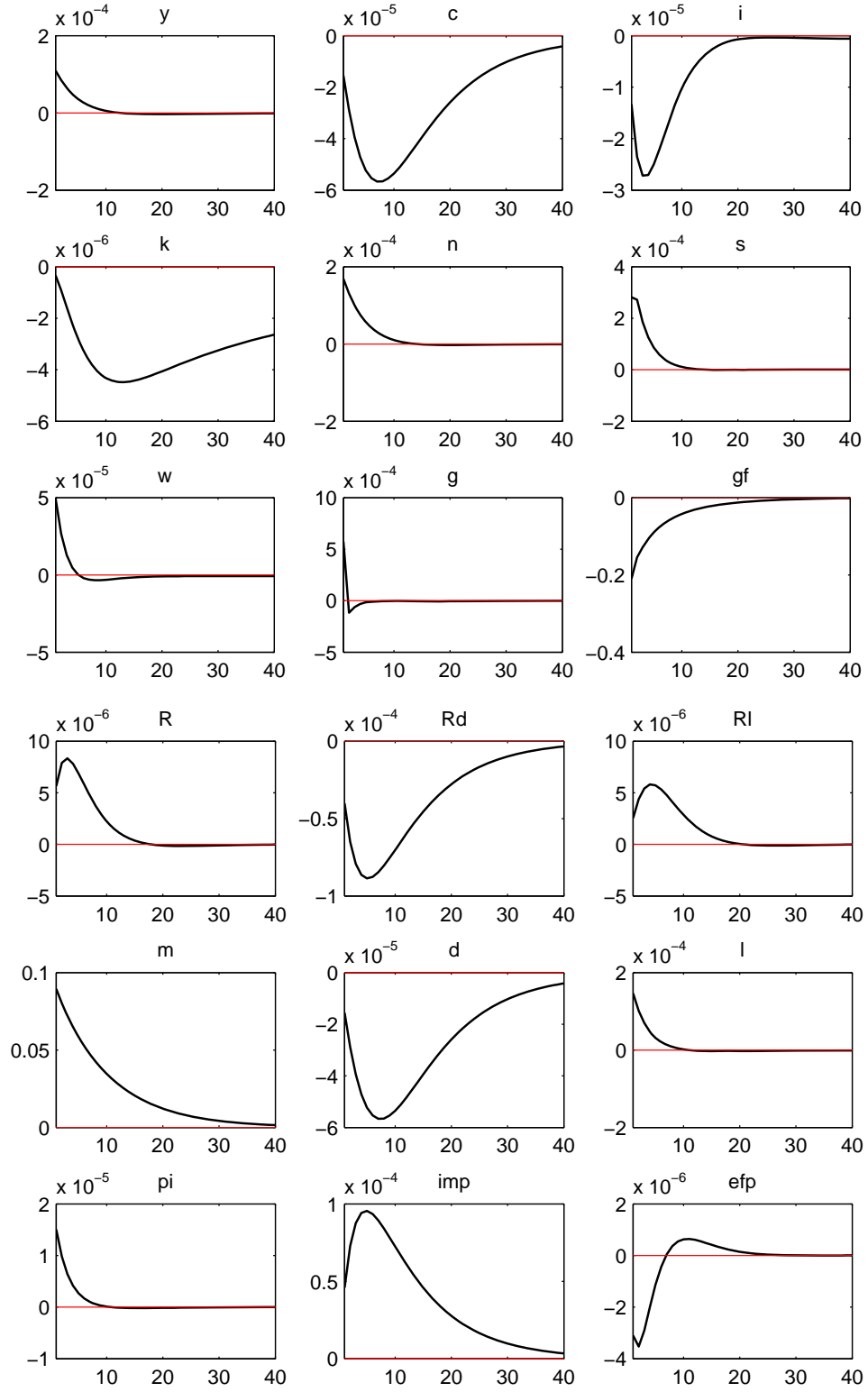
**Figure 5:** Selected impulse responses to an orthogonalised technology shock  $\varepsilon_t^\theta$  in goods production



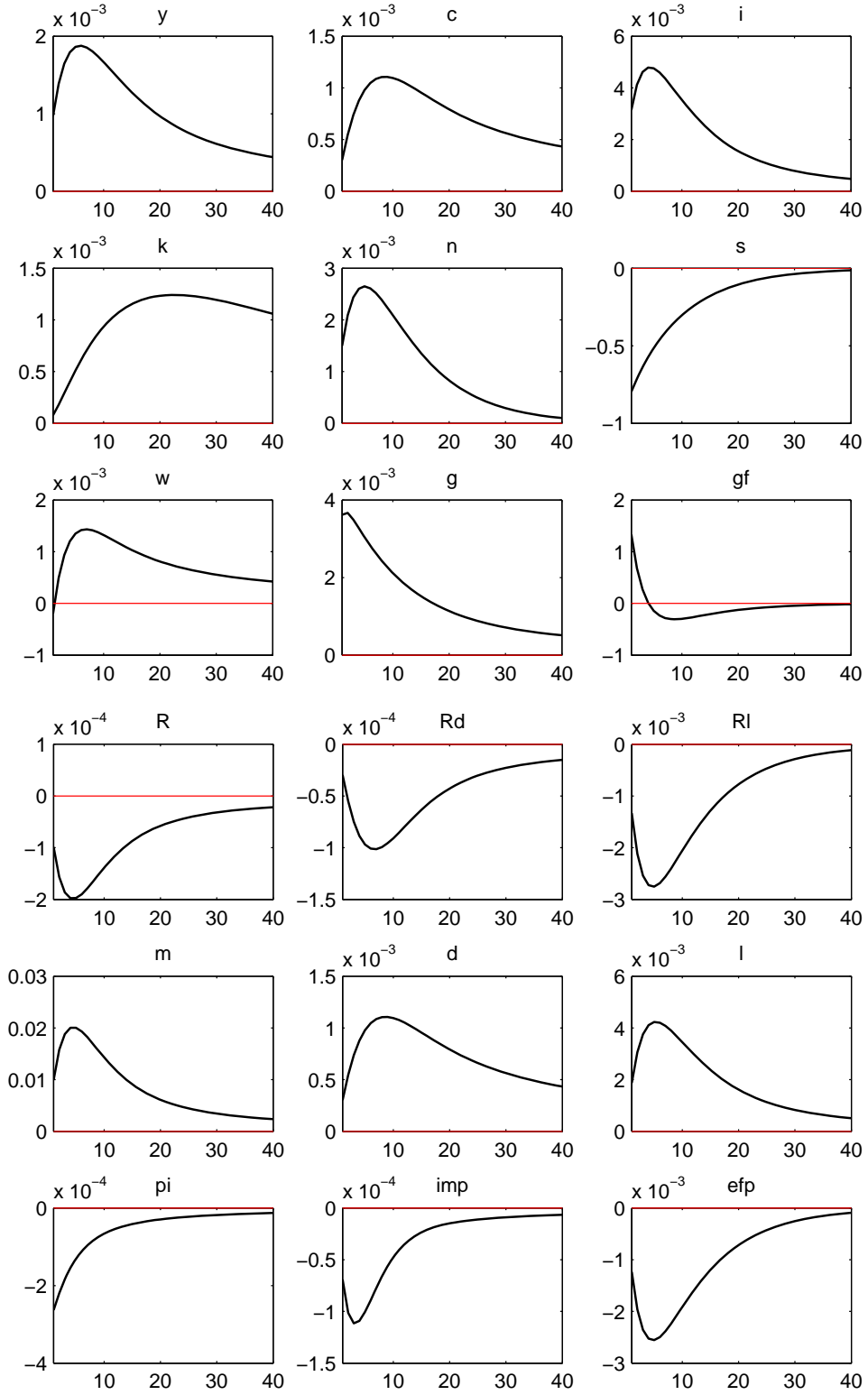
**Figure 6:** Selected impulse responses to an isolated shock  $\varepsilon_t^r$  to the monetary policy rate



**Figure 7:** Selected impulse responses to an orthogonalised Deposit-in-Advance disturbance  $\varepsilon_t^\alpha$



**Figure 8:** Selected impulse responses to an orthogonalised Inside Money Premium shock  $\varepsilon_t^\omega$



**Figure 9:** Selected impulse responses to an isolated shock  $\varepsilon_t^X$  to the External Finance Premium