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Agency Costs, Net Worth, and the Credit Channel of Monetary Transmission

by

Christian Fachat

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Bonn Graduate School of Economics
Department of Economics
University of Bonn
Adenauerallee 24 - 42
D-53113 Bonn

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Abstract

This paper presents a full model of the Credit Channel of the monetary transmission mechanism. In particular, the special role of the banking sector is derived endogenously and special attention is paid to the role of borrowers' net worth. A debt contracting problem with asymmetric information and heterogeneous borrowers is embedded in a stochastic dynamic general equilibrium model with money. In contrast to the traditional assumption, the paper assumes that agency costs arise in the production of aggregate output instead of in the investment sector. Numerical simulations of the model economy show two major points: First, the model with heterogeneous borrowers does not replicate as many stylized facts as the model without heterogeneous borrowers. Second, the model dampens the impulse response of output after a positive money supply shock, compared to the standard monetary business cycle model. Interestingly, the results of this paper differ considerably from the results of a related paper with agency costs arising in the production of the investment good.

JEL classification: E13, E32, E44, E51

Key words: financial intermediation, costly state verification, monetary transmission mechanism, credit channel, limited participation, liquidity effect

*University of Bonn, Wirtschaftstheoretische Abteilung I, Adenauerallee 24–42, D-53113 Bonn, Germany, e-mail: Christian.Fachat@uni-bonn.de.

1 Introduction

One of the main research subjects in macroeconomics during the 1990's has been the transmission mechanism of monetary policy. A lot of work was published, both theoretical and empirical. One reason for this activity is that there are many possible explanations of how money affects real activity. In contrast to the fact *that* money matters, which is established at least for the short run, the way *how* money matters is still highly controversial. The proponents of one monetary transmission mechanism, the so-called Credit Channel of monetary policy, argue that frictions in credit markets are crucial to understand how monetary policy affects the economy.[1] This Credit Channel consists of the Bank Lending Channel and the Balance Sheet Channel. The former emphasizes the fact that borrowers are "bank-dependent" in the sense that they cannot directly access public debt markets but instead have to finance their projects by loans from banks. The latter emphasizes the role of borrowers' net worth as, due to problems of adverse selection and moral hazard following from informational asymmetries, the amount borrowed does not only depend on the price of credit but also on borrowers net worth.

Until recently, there was no monetary stochastic dynamic general equilibrium model that has modeled both of the just mentioned points simultaneously and acceptably: First, in the existing models, the special role of banks is often purely ad hoc as the assumption that all borrowers can only borrow from banks is not further justified. Such an assumption should, however, be based on first principles as well as on explicitly modeled informational problems. Second and even more important, the special role of borrowers' net worth is not examined. Either there is no net worth of borrowers at all, or it is set constant. Therefore, the credit contractual arrangements cannot take into account the role of a changing net worth of borrowers.

In Fachat (2000) I solve this problem by endogenizing the special role of banks and allowing for endogenous borrowers' net worth. There, I follow the recent work of Fuerst (1995), Fisher (1999), and Cooley and Nam (1998) and embed the costly state verification framework introduced by Townsend (1979) and Gale and Hellwig (1985) into a monetary business cycle model with cash-in-advance constraint and limited participation assumption. As in Diamond (1984) there is a clear role for banks to intermediate between borrowers and households in order

[1] For the credit channel, see, e.g., Bernanke and Gertler (1995), Morris and Sellon (1995), or Hubbard (1995).

to minimize the aggregate monitoring costs. Building on the work of Carlstrom and Fuerst (1997, 1998), I model the ex ante heterogeneity of borrowers and show that for the analysis of the general equilibrium, only the mean of the net worth distribution matters. Keeping track of this first moment means adding a further state variable to the dynamic program.

Fachat (2000) follows the traditional assumption of Bernanke and Gertler (1989), Fuerst (1995), Bernanke et al. (1999), and Carlstrom and Fuerst (1997), that agency costs arise in the production of investment goods. There, I show that the agency-model with ex ante heterogeneous entrepreneurs represents a clear improvement to the standard monetary model as well as to the agency model with ex post heterogeneity only. In this paper, we will examine if this statement is also true if one assumes that agency costs arise in the production of aggregate output instead of in the investment sector. This approach follows the work of Cooley and Nam (1998), Fisher (1999), and Carlstrom and Fuerst (1998), and implies the standard assumption of the real business cycle literature that consumption and investment goods are identical and therefore the relative price of investment is identical to unity.

The remainder of the paper is organized as follows: The next section describes the economic environment and defines the general equilibrium. Then, in Section 3, we calibrate the model using long-run US data, compute the equilibrium by the method of undetermined coefficients, and discuss its quantitative effects by analyzing impulse response functions of important endogenous variables. Finally, Section 4 concludes.

2 A general equilibrium model of the credit channel

The model is a variation of the stochastic growth model with money introduced by a cash-in-advance constraint on consumption spending, a limited participation assumption, and informational asymmetries on the credit market. The economy consists of three types of agents: households, entrepreneurs, and a financial intermediary called “bank”. In addition, there is a monetary authority which performs passive monetary policy.

The households supply their labor and capital stock to the entrepreneurs, each of whom is owner of a good producing firm. In return, the households receive wage and rental payments. Each household places part of his cash holding as deposits in the financial intermediary and spends the rest for consumption. These deposits, together with the monetary injections, are channeled from the intermediary to the firms using financial contracts. The entrepreneurs use the external funds borrowed in the loan market from the intermediary and their predetermined internal funds to hire the factors of production from the households. Firms are subject to aggregate as well as to idiosyncratic productivity shocks. Each entrepreneur has ex post private information on his idiosyncratic productivity shock which other agents can verify only at a cost.

In the remainder of this section, we outline the decision problems of the agents in the model, describe the problem that determines the optimal loan contract between firms and the financial intermediary, and then we define the general equilibrium.

2.1 Households

Households are identical and infinitely-lived with preferences over consumption (C_t) and leisure $(1 - L_t)$. The representative household maximizes the expected value of a discounted stream of utility given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t, 1 - L_t), \tag{1}$$

where $\mathbb{E}_0$ is the conditional expectation operator with respect to information in period 0 and the discount factor β is between 0 and 1.

The representative household divides his beginning-of-period money holdings M_t^h between deposits D_t with the intermediary and an amount to satisfy a cash-in-advance constraint on consumption spending P_tC_t, where P_t denotes the nominal price level in period t. Deposits must be made before observing the time t aggregate shocks and consequently before the nominal gross interest rate on deposits, R_t^D, is known. All other choices are made after observing the aggregate shocks. This is the so-called "limited participation" or "sluggish cash flow" assumption due to Lucas (1990), Fuerst (1992), and Christiano (1991). The household's income is derived at the end of the period from four sources: First, there is wage income, W_tL_t, where W_t denotes the nominal wage rate. Second, the household receives income $R_t^kK_t$ from renting his capital stock, where R_t^k is the nominal rental rate on capital. Third, the household is paid interest on his deposits $R_t^DD_t$. Finally, by virtue of his ownership of the financial intermediary, the household receives nominal dividends Π_t^B. All of this income can then be spent for investment

I_t or can be hold as cash for the next period M^h_{t+1}. The resulting budget constraint of the household is

$$M^h_{t+1} = W_t L_t + R^k_t K_t + R^D_t D_t + \Pi^B_t + (M^h_t - D_t - P_t C_t) - P_t I_t, \quad (2)$$

where the term in parenthesis represents the cash left over from the consumption market, which will be zero in equilibrium.

The household's optimization problem consists of maximizing (1) subject to the sequence of budget constraints (2), cash-in-advance constraints

$$P_t C_t \leq M^h_t - D_t, \quad (3)$$

and capital accumulation conditions

$$K_{t+1} = (1-\delta)K_t + I_t, \qquad 0 < \delta < 1, \quad (4)$$

for all periods t.

With standard assumptions[2], the household's optimization problem has an interior and unique solution. This solution is characterized by the first order conditions

$$\mathbb{E}\left\{ U_{L,t} + \beta U_{C,t+1} \frac{W_t}{P_{t+1}} | \Omega_{1t} \right\} = 0, \quad (5)$$

$$\mathbb{E}\left\{ U_{C,t+1} \frac{P_t}{P_{t+1}} - \beta U_{C,t+2}[R^k_{t+1} + P_{t+1}(1-\delta)]/P_{t+2} | \Omega_{1t} \right\} = 0, \quad (6)$$

and

$$\mathbb{E}\left\{ U_{C,t} - \beta R^D_t U_{C,t+1} \frac{P_t}{P_{t+1}} | \Omega_{0t} \right\} = 0, \quad (7)$$

where the information sets Ω_{0t} and Ω_{1t} are defined as follows:

- Ω_{0t} includes the aggregate capital stock K_t, the pre-determined amounts of cash holding M^h_t and M^e_t, and the values of all economy-wide variables dated t-1 and earlier,
- Ω_{1t} includes Ω_{0t} and the period t realizations of the aggregate technology shock θ_t and of the aggregate monetary shock χ_t.

The Euler-Equation (5) determines the household's labor decision. The accumulation of physical capital is governed by Equation (6). The Euler-Equation (7)

[2]See, e.g. King et al. (1988)

results from the household's saving decision. This decision is made conditional on Ω_{0t} as, with limited participation, the household is unable to respond to current shocks by changing current deposits. Given the deposits D_t, the price level P_t, and the beginning-of-period cash holding of the household M_t^h, consumption C_t is then determined as residual by the cash-in-advance constraint (3).

2.2 Firms

The economy contains a continuum of infinitely-lived, risk-neutral entrepreneurs with unit mass and each entrepreneur is indexed by $i \in [0, 1]$. Each entrepreneur owns a firm and has access to a constant-returns-to-scale production technology.[3] He hires workers and capital to produce goods according to this technology. All firms are subject to idiosyncratic productivity shocks as well as to an aggregate technology shock. The production function of firm i is given by

$$Y_{it} = \omega_{it} f(\theta_t, K_{it}, H_{it}) = \omega_{it} \theta_t K_{it}^{\alpha} H_{it}^{1-\alpha}, \tag{8}$$

with $0 < \alpha < 1$. Here ω_{it} denotes the idiosyncratic productivity disturbance, θ_t denotes the economy-wide technology shock, and K_{it} and H_{it} denote the firm-level capital and employment demands, respectively. The random variable ω is assumed to be independent and identically distributed across time and firms, with cumulative probability distribution function Φ, continuous probability density function ϕ, a nonnegative support, and a mean of unity. The aggregate technology shock θ_t is assumed to evolve over time according to

$$\log \theta_t = (1 - \rho_\theta) \log \bar{\theta} + \rho_\theta \log \theta_{t-1} + \epsilon_{\theta,t},$$

where $0 < \rho_\theta < 1$ and $\epsilon_{\theta,t}$ is an independent and identically distributed shock. The constant $\bar{\theta}$ is the nonstochastic steady state value of θ.

The realization of the aggregate technology shock is known at the beginning of the period, when production decisions have to be made. Each entrepreneur uses external funds from the loan market as well as its net worth to finance his input bill. The entrepreneur's internal funds consist of the beginning-of-period accumulated cash holding M_{it}^e, carried over from period $t - 1$.[4] After writing

[3] In the following, the terms entrepreneur and firm are used synonymously.

[4] To be more precise, net worth has to include an arbitrary small share of income which is out of the control of the firm. This could be, e.g., labor income from working for other firms or a share of the new money received from the monetary authority. Otherwise, a firm once having become bankrupt, could never again finance a project: As it is shown by equation (13), with no cash holding, the firm would not get any credit. Because modeling this additional income has no effect on the model dynamics, we ignore it for simplicity.

the credit contract with the financial intermediary and after hiring the production inputs labor and capital, the idiosyncratic shocks are realized and learnt costlessly by the respective entrepreneur. Then, knowing the realization of his own shock ω_{it}, each entrepreneur i produces goods according to (8), sells them on the final goods markets, and repays the loan according to the financial contract outlined in Section 2.3.

Let B_{it} denote firm's i nominal input bill, defined by

$$B_{it} = W_t H_{it} + R_t^k K_{it}.$$

Then, the necessary external financing is equal to $(B_{it} - M_{it}^e)$. Given internal funds and external funds adding up to B_{it}, cost minimization implies for the respective capital and labor demands

$$K_{it} = \alpha \frac{B_{it}}{R_t^k} \qquad \text{and} \qquad H_{it} = (1-\alpha)\frac{B_{it}}{W_t}.$$

Substituting these factor demands into equation (8) defines the indirect production function $\tilde{f}$ of firm i and output as a function of B_{it}:

$$\begin{aligned} Y_{it} &= \omega_{it}\theta_t \left(\frac{\alpha}{R_t^k}\right)^{\alpha} \left(\frac{(1-\alpha)}{W_t}\right)^{1-\alpha} B_{it}, \\ &= \omega_{it}\tilde{f}(\theta_t, R_t^k, W_t) B_{it}, \end{aligned}$$

with $\tilde{f}(\theta_t, R_t^k, W_t) = \theta_t(\alpha/R_t^k)^{\alpha}((1-\alpha)/W_t)^{1-\alpha}$. The output level of an entrepreneur i is uniquely identified, given the realizations of the idiosyncratic productivity shock ω_{it}, the aggregate technology shock θ_t, the prices of capital and labor R_t^k and W_t, and the nominal input bill B_{it}. The first four are out of the control of a single entrepreneur. Therefore, each entrepreneur has only to decide which project size B_{it} to choose.

At the end of the period, after all other transactions have been made and if the entrepreneur has still any profits left, he can decide whether to use these means for consumption or for carrying cash into the next period. Formally, he maximizes his expected lifetime utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} (\beta\gamma)^t C_{it}^e, \tag{9}$$

with $0 < \gamma < 1$, and subject to the sequence of budget constraints

$$M_{it+1}^e = P_t \omega_{it} \tilde{f}(\theta_t, R_t^k, W_t) B_{it} - R_t^l (B_{it} - M_{it}^e) - P_t C_{it}^e, \tag{10}$$

where R_t^l is the interest rate on loans, which will be determined in the next subsection by the financial contract with the intermediary. If the firm has no profits left after repaying its loan, so that the first two terms on the right hand side of Equation (10) sum up to zero, consumption and cash holding are also zero, $C_{it}^e = 0$ and $M_{it+1}^e = 0$. Assuming an interior solution, this utility maximization problem implies the following Euler-equation

$$\mathbb{E}\left\{1 - \beta\gamma \frac{R_{t+1}^D P_t \tilde{f}(\theta_{t+1}, R_{t+1}^k, W_{t+1}) E^b(\bar{\omega}_{it+1})}{R_{t+1}^D - P_{t+1}\tilde{f}(\theta_{t+1}, R_{t+1}^k, W_{t+1}) E^l(\bar{\omega}_{it+1})} |\Omega_{1t}\right\} = 0, \qquad (11)$$

where $E^b(\bar{\omega}_i)$ and $E^l(\bar{\omega}_i)$ are the fractions of the expected output received by the entrepreneur and the financial intermediary, respectively.[5]

2.3 Financial intermediary

The single financial intermediary called "bank" is owned by the households. Its role is to co-ordinate lending from consumers to entrepreneurs. It receives deposits from consumers and lump sum payments from the monetary authority, where the latter represents the injection of new money into the economy. The bank's assets can be lent to the entrepreneurs. The intermediary behaves competitively in the deposit market. Therefore, the bank treats the gross rate of interest on deposits, R^D, as a parameter and assumes it can obtain whatever funds it needs at that rate. The gross interest rate is therefore the fixed opportunity costs of funds for the bank.

In contrast to the entrepreneurs, each of whom learning the realization of his idiosyncratic productivity shock costlessly, the intermediary can observe the shock by expending a nominal monitoring cost that is proportional to the expected revenue from selling the produced output, $\mu P_t \tilde{f}(\theta_t, R_t^k, W_t) B_{it}$.

This informational structure is the static model of costly state verification of Townsend (1979). The fact that entrepreneurs observe the idiosyncratic productivity shock privately creates a moral hazard problem with external finance as, absent monitoring, a borrowing entrepreneur may wish to under-report the true value of the shock ω_{it} in order to reduce his debt repayment. In order to avoid modeling a game with repeated moral hazard in a multi-period contracting problem, we assume that there is enough inter-period anonymity in financial markets so that credit contracts between borrowers and lenders can be written contingently only

[5] Both functions will be defined in Section 2.3.

on the current level of net worth and not on the entire past of debt repayments.[6] Time subscripts are therefore dropped for the rest of this section.

In the following, we concentrate on standard debt contracts, which are shown to be optimal for such an environment by Gale and Hellwig (1985) and Williamson (1987).[7] A standard debt contract specifies a fixed repayment, or equivalently a fixed interest rate on loans R^l, which is paid by a solvent borrower. In contrast, if the borrower declares to be bankrupt, what happens if and only if he is unable to pay back his debt, the intermediary will monitor the borrower and confiscate all the entrepreneur's assets. Note that the contract is completely defined by a critical or cut-off value $\bar{\omega}_i = R^l(B_i - M_i^e)/(P\tilde{f}(\cdot)B_i)$ and the project size B_i. With this notation, the declaration of bankruptcy is, in equilibrium, equivalent to a true realization of the idiosyncratic shock of $\omega_i < \bar{\omega}_i$. In the opposite case, $\omega_i \geq \bar{\omega}_i$, the loan is repaid and the firm keeps the excess revenue. In the following we will consider the optimization problem over these two arguments $(\bar{\omega}_i, B_i)$.

For a standard debt contract, the expected income of a borrower and the expected income of the lender are given, respectively, by

$$\begin{aligned}
&\int_{\bar{\omega}_i}^{\infty} (P\omega_i \tilde{f}(\theta, R^k, W)B_i - R^l(B_i - M_i^e))\Phi(d\omega_i) \\
&\qquad = P\tilde{f}(\theta, R^k, W)B_i \left[\int_{\bar{\omega}_i}^{\infty} \omega_i \Phi(d\omega_i) - (1 - \Phi(\bar{\omega}_i))\bar{\omega}_i\right] \\
&\qquad = P\tilde{f}(\theta, R^k, W)B_i E^b(\bar{\omega}_i),
\end{aligned}$$

and

$$\begin{aligned}
&\int_0^{\bar{\omega}_i} (P\omega_i \tilde{f}(\theta, R^k, W) - \mu P\tilde{f}(\theta, R^k, W)B_i)\Phi(d\omega_i) + \int_{\bar{\omega}_i}^{\infty} (R^l(B_i - M_i^e))\Phi(d\omega_i) \\
&\qquad = P\tilde{f}(\theta, R^k, W)B_i \left[\int_0^{\bar{\omega}_i} \omega_i \Phi(d\omega_i) - \mu\Phi(\bar{\omega}_i) + (1 - \Phi(\bar{\omega}_i))\bar{\omega}_i\right] \\
&\qquad = P\tilde{f}(\theta, R^k, W)B_i E^l(\bar{\omega}_i),
\end{aligned}$$

where the second line in both blocks follows from using the definition of $\bar{\omega}_i$ and $E^b(\bar{\omega}_i)$ and $E^l(\bar{\omega})$ are defined by the respective terms in brackets.

[6] The same assumption was made by Carlstrom and Fuerst (1997, 1998) and Bernanke et al. (1999) in similar environments.

[7] For this optimality, we must assume that a commitment device exists and restrict the analysis to pure strategies, so that monitoring is a deterministic function of the state. Boyd and Smith (1994) show that the exclusion of stochastic monitoring is with little loss of generality.

The optimal contract maximizes the expected payoff to the informed entrepreneur, subject to the payoff to the uninformed intermediary being at least larger than its opportunity costs. The optimal contract is thus given by the $(\bar{\omega}_i, B_i)$ pair that solves

$$\max_{\bar{\omega}_i \geq 0, B_i \geq 0} P\tilde{f}(\theta, R^k, W)B_i E^b(\bar{\omega}_i),$$

subject to

$$P\tilde{f}(\theta, R^k, W)B_i E^l(\bar{\omega}_i) \geq R^D(B_i - M_i^e),$$

taken as given the prices P, R^k, W, the interest rate on deposits R^D, the individual net worth M_i^e, and the aggregate technology shock θ.

Solving this maximization problem leads us to the two following first-order conditions

$$1 - \Phi(\bar{\omega}_i)\mu + \phi(\bar{\omega}_i)\mu \frac{E^b(\bar{\omega}_i)}{E^{b\prime}(\bar{\omega}_i)} = \frac{R^D}{P} / \tilde{f}(\theta, R^k, W) \tag{12}$$

and

$$B_i = \frac{R^D}{R^D - P\tilde{f}(\theta, R^k, W)E^l(\bar{\omega}_i)} M_i^e, \tag{13}$$

where $E^{b\prime}(\cdot)$ is the derivative of the function $E^b(\cdot)$. Equation (12) defines the implicit function

$$\bar{\omega}_i = \bar{\omega}(\theta, P, R^D, R^k, W), \tag{14}$$

with $\bar{\omega}_\theta > 0, \bar{\omega}_P > 0, \bar{\omega}_{R^D} < 0, \bar{\omega}_{R^k} < 0$, and $\bar{\omega}_W < 0$, where $\bar{\omega}_x$ is the partial derivative of the function $\bar{\omega}(\cdot)$ with respect to the variable x. Plugging the Function (14) into the first-order Condition (13), we get the solution for the project size B_i of firm i:

$$B_i = B(\theta, P, R^D, R^k, W, M^e), \tag{15}$$

with $B_\theta > 0, B_P > 0, B_{R^D} < 0, B_{R^k} < 0, B_W < 0$, and $B_{M^e} > 0$.

As mentioned in the introduction, the existence of the intermediary should be based on first principles. Diamond (1984) and Williamson (1986) show how intermediation may arise as an equilibrium outcome in related but richer settings. Instead of a formal proof, we only give the intuition that this is likely to be true in our framework as well. The key to understanding why there is a benefit from intermediation is diversification within the financial intermediary. The intermediary performs a “delegated monitoring” to avoid duplication of monitoring and to minimize aggregate monitoring costs. Not every entrepreneur is monitored but every borrowers is monitored at most once. In the case of direct lending, each borrower borrows from several households and each of these lenders monitors in the case of default. A financial intermediary, which lends to a large number of borrowers, eliminates this duplication. The cost of delegation, per entrepreneur monitored, varies inversely with the number of intermediary's borrowers and eventually approaches zero as the number of borrowers goes to infinity. As Diamond (1984) emphasizes financial intermediaries allow better contracts to be used and allow Pareto superior allocations. Intermediation then drives direct lending out of the system in equilibrium.

Therefore, in contrast to standard monetary business cycle models without agency problems, such as Christiano and Eichenbaum (1995) or Cooley and Hansen (1995), here the existence of the financial intermediary is based on first principles. Hence, in our model with asymmetric information on the credit market, the assumption that only indirect lending through banks is possible is well justified.

2.4 Monetary Authority

The monetary authority is the central bank, which supplies reserves to the banking sector. We do not allow the central bank to perform active endogenous monetary policy. Instead we assume that reserves are supplied such that the growth rate of money supply $\chi_t = M^s_{t+1}/M^s_t$ follows the first-order autoregressive process

$$\log \chi_t = (1 - \rho_\chi) \log \bar{\chi} + \rho_\chi \log \chi_{t-1} + \epsilon_{\chi,t}, \tag{16}$$

with $0 < \rho_\chi < 1$. The random variable $\epsilon_{\chi,t}$ is an independent and identically distributed shock and the nonstochastic steady state money growth rate is $\bar{\chi}$. The innovation $\epsilon_{\chi,t}$ is assumed to be mutually uncorrelated with the technology and monetary shock innovations at all leads and lags.

2.5 General equilibrium

In this section, we will first derive some aggregation results in order to facilitate the computation of the general equilibrium. Then the general equilibrium of our model economy will be defined.

Computation of equilibria in models with heterogeneous agents is usually more difficult than in standard representative-agent models.[8] In these models, the equilibrium laws-of-motion become functions not only of aggregate variables, but

[8] For a comprehensive overview of dynamic general equilibrium models with heterogeneous agents see Ríos-Rull (1995).

also of the distribution of these variables across different types of agents. Solving for the laws-of-motion of such distributions is a nontrivial task. In our underlying setting, the linearity assumptions concerning the production technology of the entrepreneurs and concerning the monitoring technology of the financial intermediary simplify the aggregation considerably. In the credit contractual arrangement we see that the Function (14) is independent of the individual level of cash holding M^e_{it}. Therefore the equilibrium bankruptcy probability is the same across all firms: $\bar{\omega}_{it} = \bar{\omega}_{jt} = \bar{\omega}_t \forall i, j$. This independence implies two simplifications. First, with the linearity of Equation (13), the project size aggregates: The aggregate project size B_t depends only on economywide identical variables: the aggregate technology shock θ_t, the price level of output P_t, the interest rate of deposits R^D_t, the nominal rental rate of capital R^k_t, the nominal wage rate W_t, and the cash holding of the entrepreneurial sector M^e_t, so that

$$B_t = B(\theta_t, P_t, R^D_t, R^k_t, W_t, M^e_t). \tag{17}$$

Second, with $\bar{\omega}$ identical for all entrepreneurs, the Euler-Equation (11) is independent of any firm specific variables and therefore identical for all solvent entrepreneurs, whatever their individual cash holding might be.

These two simplifications imply that for the analysis of the general equilibrium of the aggregate economy, we do not need to model either any level of individual net worth or the distribution of net worth across entrepreneurs. In addition to the representative Euler-Equation (11) of the entrepreneurial sector and the Function (17) defining the aggregate project size, we just have to keep track of the aggregate level of entrepreneurial net worth or cash holding, which is easily done by adding a further state variable to the dynamic program. The law-of-motion for this variable, the aggregate entrepreneurial cash holding M^e_t, is given by integrating the entrepreneurs' budget constraint over all entrepreneurs

$$M^e_{t+1} = P_t Y_t E^b(\bar{\omega}_t) - P_t C^e_t,$$

where C^e_t denotes aggregate entrepreneurial consumption.

We now come to the definition of the general equilibrium. But before, we have to transform nominal variables to induce stationarity by dividing them by the money supply at the beginning of the period, M^s_t:[9]

$$p_t = P_t/M^S_t, \quad d_t = D_t/M^S_t, \quad w_t = W_t/M^S_t, \quad r^k_t = R^k_t/M^S_t, \quad \pi^B_t = \Pi^B_t/M^S_t,$$
$$m_t = M_t/M^S_t, \quad m^h_t = M^h_t/M^S_t, \quad m^e_t = M^e_t/M^S_t \quad b_t = B_t/M^s_t.$$

[9]See, e.g., Cooley and Hansen (1995) for details of the normalization.

A rational expectations equilibrium can be defined in the usual way. It consists of time invariant aggregate allocation functions $\{C, L, K, H, I, d, m^h, C^e, m^e, B\}$ and pricing functions $\{p, w, R^D, r^k, \bar{\omega}\}$ of the relevant state such that given these rules agents' optimization satisfies market clearing. Deposits d are a function of Ω_{0t} whereas all other price and allocation rules are functions of the elements of Ω_{1t}, where Ω_{0t} and Ω_{1t} are defined as in Section 2.1.

The general equilibrium is then characterized by the seven Euler equations:

$$0 = \mathbb{E}\left\{U_{L,t} + \beta U_{C,t+1}\frac{w_t}{p_{t+1}\chi_t}|\Omega_{1t}\right\}, \tag{18}$$

$$0 = \mathbb{E}\left\{U_{C,t+1}\frac{p_t}{p_{t+1}\chi_t} - \beta U_{C,t+2}\frac{r^k_{t+1} + p_{t+1}(1-\delta)}{p_{t+2}\chi_{t+1}}|\Omega_{1t}\right\}, \tag{19}$$

$$0 = \mathbb{E}\left\{U_{C,t} - \beta R^D_t U_{C,t+1}\frac{p_t}{p_{t+1}\chi_t}|\Omega_{0t}\right\}, \tag{20}$$

$$0 = \mathbb{E}\left\{1 - \beta\gamma\frac{R^D_{t+1}p_t\tilde{f}(\theta_{t+1}, r^k_{t+1}, w_{t+1})E^b(\bar{\omega}_{t+1})}{\chi_t(R^D_{t+1} - p_{t+1}\tilde{f}(\theta_{t+1}, r^k_{t+1}, w_{t+1})E^l(\bar{\omega}_{t+1}))}|\Omega_{1t}\right\}, \tag{21}$$

$$r^k_t = \alpha\frac{b_t}{K_t}, \tag{22}$$

$$w_t = (1-\alpha)\frac{b_t}{H_t}, \tag{23}$$

combined with the market clearing conditions

$$K_{t+1} = (1-\delta)K_t + I_t, \tag{24}$$

$$Y_t = C_t + C^e_t + I_t, \tag{25}$$

$$H_t = L_t, \tag{26}$$

$$m_t = m^h_t + m^e_t = 1, \tag{27}$$

$$b_t - m^e_t = d_t + m_{t+1}\chi_t - m_t, \tag{28}$$

and the other conditions

$$\frac{R^D_t}{p_t}/\tilde{f}(\theta_t, r^k_t, w_t) = 1 - \Phi(\bar{\omega}_t)\mu + \phi(\bar{\omega}_t)\mu\frac{E^b(\bar{\omega}_t)}{E^{b\prime}(\bar{\omega}_t)} \tag{29}$$

$$b_t = \frac{R^D_t}{R^D_t - p_t\tilde{f}(\theta_t, r^k_t, w_t)E^l(\bar{\omega}_t)}M^e_t, \tag{30}$$

$$m^e_{t+1}\chi_t = p_t Y_t E^b(\bar{\omega}_t) - p_t C^e_t, \tag{31}$$

$$Y_t = \theta_t K^\alpha_t H^{1-\alpha}_t, \tag{32}$$

$$p_t C_t = m_t - d_t. \tag{33}$$

Equations (18), (19), and (20) are the Euler equations of the households' maximization problem. Equation (21) is the Euler-Equation of the entrepreneurs' utility maximization problem and Equations (22) and (23) result from their costs minimization problem. Equations (24) to (28) are the market clearing conditions for the capital market, output market, labor market, money market, and the credit market, respectively. Equations (29) and (30) are the first order conditions from the credit contractual problem, whereas Equation (31) is the law-of-motion for the aggregate entrepreneurial cash holding. Equations (32) and (33) are the aggregate production function and the household's cash-in-advance constraint, respectively.

3 Quantitative properties

In this section I will describe the quantitative properties of the model economy. As the model is too complicated to be solved analytically, it will be solved and analyzed numerically. Before computing the equilibrium, we require values for the model's parameters, which will be assigned in the next subsection. Then the solution technique can be applied. Afterwards, in Subsection 3.3, the quantitative properties will be analyzed by discussing impulse responses of important endogenous variables.

3.1 Calibration

The values of the model's structural parameters $\beta, \lambda, \alpha, \delta, \bar{\chi}, \rho_{\chi}, \bar{\theta}, \rho_{\theta}, \mu, \sigma_{\omega}$, and γ are chosen by matching the non-stochastic steady state equilibrium of the model economy with the long-term properties of post-war US time series. To the extent possible, the model is calibrated following the principles laid out in Kydland and Prescott (1996) and Cooley (1997).

The time period is assumed to be one quarter. For the experiments, we use a household utility function of the Cobb-Douglas type, so that $U(C_t, L_t) = \lambda \log C_t + (1-\lambda)\log(1-L_t)$. Following Christiano (1991), I set the parameter λ such that the ratio of non-market to market time $L/(1-L)$ matches the empirical value of 0.28. This implies $\lambda = 0.251$. The mean of the growth rate of money supply, $\bar{\chi}$, is set equal to 1.0119, a value estimated by Christiano and Eichenbaum (1995). The subjective utility discount rate of the household β follows from the non-stochastic version of the Euler-Equation (20). With the nominal interest rate of deposits R^D set to 8.05%, it follows that $\beta = 0.9925$.

The parameters α and $(1-\alpha)$ correspond to the shares of capital income and labor income on aggregate income. Estimations by Christiano (1988) show that the corresponding empirical shares are approximately 0.36 and 0.64, respectively, so that we set $\alpha = 0.36$. Concerning the quarterly depreciation rate, we assume $\delta = 0.0212$, an estimate also calculated by Lawrence Christiano in Christiano (1991).

In quantifying the autocorrelation coefficients of the law-of-motions of the aggregate shocks, we follow Christiano (1991) and others by using $\rho_\chi = 0.32$ and the typical business cycle literature by setting $\rho_\theta = 0.95$. The value of $\bar{\theta}$ is simply a matter of normalization, and is set to 1.

As already mentioned in Section 2, the financial intermediary performs the monitoring if and only if a borrower defaults on his loans. Therefore, the monitoring costs could be interpreted as bankruptcy costs. Trying to match the parameter μ with empirical evidence shows that there is a great variety of results within the empirical literature on this value. It ranges from 1% to 36% of the firm's assets.[10]. We set $\mu = 0.15$, a choice roughly in the middle which was also used by Fachat (2000) and Carlstrom and Fuerst (1998).[11]

As for the distribution Φ, we assume that it is log-normal with a mean of unity and a standard deviation of σ_ω.

The last two parameters σ_ω and γ are treated as unobservable and chosen indirectly to match the annual risk premium, defined as the spread between the prime rate and the three-month commercial paper rate, of 187 basis points and the quarterly bankruptcy rate of 0.998%. Matching the two empirical risk measures implies $\sigma_\omega = 0.207$ and $\gamma = 0.96762$.

The parameter choices are summarized in Table 1.

3.2 Solution

The model is solved numerically. First, the necessary Euler-equations, market clearing conditions, and other equations characterizing the equilibrium, Equations (18) to (33), are log-linearized about the non-stochastic steady state equilibrium of the model. Then, the recursive equilibrium law of motion for the endogenous variables is calculated using the method of undetermined coefficients.

[10] Some of the relevant estimates are: Warner (1977): 1% to 5.3 %, Altman (1984): 11 to 17%, Guffey and Moore (1991): 9.12%, Alderson and Betker (1995): 36%.

[11] Carlstrom and Fuerst (1997), Fisher (1999), and Fuerst (1995) use higher values for μ (.25, .2, and .2, respectively), whereas Cooley and Nam (1998) use the lower value $\mu = .0912$.

Function		
$U(C_t, L_t) = \lambda \log C_t + (1-\lambda)\log(1-L_t)$ $\omega \sim \log\mathcal{N}(1, \sigma_\omega)$		
Parameter	**Value**	**Identification condition and/or Source**
λ	0.251	$L/(1-L) = 0.28$, Christiano (1991)
β	0.9925	$R^D = 8.05\%$, Cooley and Nam (1998)
α	0.36	share of income going to capital, Christiano (1988)
δ	0.0212	Christiano (1991)
$\bar{\theta}$	1	normalization
ρ_θ	0.95	typical RBC literature
$\bar{\chi}$	1.0119	Christiano and Eichenbaum (1995)
ρ_χ	0.32	Christiano (1991)
μ	0.15	empirical evidence on bankruptcy costs
σ_ω	0.207	} annual risk premium = 187 basis points
γ	0.96762	} quarterly bankruptcy rate = 0.998%

Table 1: Parameter values.

3.3 Simulation

We are now ready for the numerical analysis of our model. The objective is to provide a quantitative evaluation of the credit channel interpretation of the monetary transmission mechanism. Special attention is paid to the role of borrowers' net worth, as this aspect is neglected in the existing monetary models in the literature, except the work of Fachat (2000). We compare the impulse responses of a monetary shock for the model of Section 2 with the impulse responses of two reference models. The first reference model is a monetary business cycle model with limited participation assumption but without agency issues. It is derived from the framework of Section 2 by setting all idiosyncratic productivity shocks ω_i equal to their mean of unity and eliminating monitoring costs by setting $\mu = 0$. In the second reference model the cash holding of the firms is set constant at its steady state value. Therefore, borrowers cannot transfer wealth endogenously from one period to the next but are instead forced to consume their whole remaining income at the end of each period. The comparison of the results of the agency costs model with entrepreneurial cash holding with the results of the just described reference models allows us to analyze the role of firms' cash holding and therefore of the possibility of endogenous net worth accumulation.

Both reference models correspond roughly to two models found in the literature. The first reference model is very similar to the model of Christiano and Eichenbaum (1992b), which itself is a simplified version of the model in Christiano and Eichenbaum (1995). The second reference model, the model where firms' cash holding rests unchanged, corresponds roughly to the model of Cooley and Nam (1998). The main differences between the two reference models on the one side and the two corresponding models in the literature on the other side are, besides different parameter values, the following: In the two literature models it is assumed that wage earnings are also available to finance consumption at the beginning of the period. This implies a different cash-in-advance constraint. Furthermore, the authors of the two articles assume that the firms are owned by the representative household and that the firms' net cash position is distributed to the household at the end of each period. In addition, Cooley and Nam (1998) do not use a Cobb-Douglas utility function but a more general CES-form. Finally, they assume that the idiosyncratic productivity shocks of the firms are uniformly distributed around a mean of unity, and not according to a log-normal distribution, as it is done in this paper.

Figures 1 to 8 describe the impulse responses of important endogenous variables to a one-time shock in the growth rate of the money supply for all three models. To be more precise, it is assumed that the money growth rate χ_t follows the law-of-motion (16) and that the shock in question $\epsilon_{\chi,0} = 0.01$ appears in period 0 and is 1% in size. In the following periods ϵ_χ is assumed to be zero again. Although this is a single one-time shock, because money growth is autocorrelated, the growth rate will stay above trend for several quarters.

With the help of the figures, we can analyze if the models are able to reproduce the stylized facts of monetary policy. Christiano and Eichenbaum (1992a), Christiano and Eichenbaum (1995), and Christiano et al. (1996) identify for the US economy the following four important facts: An expansive money supply shock leads to an increase of employment, aggregate output, and real wages and to a decrease of nominal interest rates. As shown by Figures 1, 2, and 3, respectively, employment, output, and real wages increase in all three models. The three stylized facts are therefore replicated in each model. Concerning the forth fact, Figures 4 and 5 show that in the agency costs model of Section 2 both nominal interest rates, the interest rate of loans and the interest rate of deposits, increase after a positive money supply shock. This stands in clear contrast to the stylized facts. In contrast, in both reference models the interest rates decrease and therefore in these models the fourth stylized fact is also well reproduced.

As the reference models correspond roughly to the models of Christiano and

Eichenbaum (1992b) and Cooley and Nam (1998), it is interesting to analyze if these literature models behave similarly. In both literature models, a positive money supply shock leads also to a temporary increase in employment and a temporary decrease in nominal interest rates. In the following period, both responses are reverse, as it is also the case in the reference models. The responses of real wages are also qualitatively similar across all four models: The decrease of real wages in the period after the monetary shock is slightly weaker in the reference models than in the two literature models. The response of household consumption in the reference models, shown in Figure 6, is, however, significantly different from that in the literature. The respective responses in Christiano and Eichenbaum (1992b) and Cooley and Nam (1998) are similar to the response of real wages, as after an initial increase it falls on a level below steady state. In the reference model, consumption must decrease in the period of the shock as consumption spending is predetermined by the cash-in-advance constraint and the output price level increases, as shown by Figure 7. This different response is therefore due to the difference in the cash-in-advance constraint. To conclude, in spite of the modeling differences across the four models without endogenous net worth accumulation, the results are quite similar.

In the following, we try to explain the different impulse response behavior of nominal interest rates across the models of this paper. Above, the respective responses have been shown to be positive in the agency costs model of Section 2 and negative in the two reference models. As it will be shown, the differences follow from the fact that in the models, different effects drive the interest rates up and down. Dependent on which effect is or which effects are stronger, the resulting interest rate response is negative or positive. To be more precise, in all three models there is a liquidity effect, a loan demand effect, and an anticipated inflation effect. The first effect drives the nominal interest rates down, whereas the two others put upward pressure on the interest rates. Furthermore, in the model with entrepreneurial cash holding, there is a forth effect, a substitution effect, which amplifies the loan demand effect.

I will now describe the four effects and the resulting dynamics in more detail. According to the *liquidity effect*, which appears in all three models, a positive monetary injection leads to a decrease of nominal interest rates. This follows from the following chain of thoughts: The new money, issued by the monetary authority, enters the economy through a direct transfer to the bank. This increases the liquidity of the banking sector. In particular, the liquidity or the supply of loans raises by the full amount of the new money as the household is unable to change his deposits at this point in time. In equilibrium, the bank lends all of these means to the firms.[12] This increase in the supply of loans decreases ceteris paribus the price of loans, that is the nominal interest rate of loans.

The second effect, which I call *loan demand effect*, leads to a change in the demand of loans on part of the firms. This effect also appears in all three models. But in contrast to the liquidity effect, a monetary expansion leads here to an increase of the nominal interest rates. This increase could be justified as follows: An expansive money supply leads, e.g., to an increase of the price level and the nominal factor costs. According to Equation (17), this increase leads to an increase in the aggregate project size and, with an unchanged entrepreneurial cash holding, to an increase in the demand for nominal loans. This implies that the price of loans, the respective interest rate, potentially increases.

Furthermore, there is a second upward pressure on interest rates due to the so-called *anticipated inflation effect*. Because of the autocorrelation coefficient of the money growth rate being positive, $\rho_\chi > 0$, the monetary growth continues to be high relative to its steady state level after the one-time shock. This increases the agents' expectation of future inflation and adds an inflation premium to prices and interest rates. This exerts countervailing pressure on nominal interest rates, compared to the liquidity effect of monetary policy.

The forth effect, the *substitution effect*, amplifies the loan demand effect and therefore also potentially increases the nominal interest rates after a positive monetary injection. In contrast to the three other effects, the substitution effect works only in the agency costs model with entrepreneurial cash holding as it follows from the endogenous consumption decision of the entrepreneurs, which is only possible in this model. The effect works as follows: As already mentioned, the money shock leads to an increase of the general price level. This increase induces that present consumption has become relatively more expansive for the entrepreneurs and that cash holding has become less expensive, both compared to the steady state. Therefore, a risk neutral entrepreneur wants to gain from this situation, postpones consumption into the future and therefore substitutes present with future consumption. This is done by decreasing present consumption and increasing individual entrepreneurial cash holding or net worth.[13] The increase in

[12] This happens in fact only as long as the nominal interest rate on loans, R_t^l, exceeds unity. In the underlying numerical simulations this inequality is always fulfilled in all three models.

[13] But, as Figure 8 shows, aggregate entrepreneurial net worth decreases after the monetary shock. This is due to the fact, that the bankruptcy rate increases after a positive money supply shock and therefore less firms do in fact hold cash, but each solvent firm holds more cash than in steady state. Aggregate borrowers' net worth then moves back to the steady state as the bankruptcy rate returns back to steady state.

firms' cash holding increases the demand of loans and therefore also potentially increases the interest rate of loans.

Up to now, I explained the four effects and the resulting dynamics. In the following, I analyze which effect dominates in which model, based on the respective impulse responses and starting with the reference models. As already mentioned and as shown by Figures 4 and 5 respectively, the interest rate on loans as well as the interest rate on deposits decrease in both reference models. The first point to mention is that in these models the substitution effect does not appear as the entrepreneurs cannot intertemporally substitute consumption. Furthermore we know from the above description that the only effect pushing down the nominal interest rates is the liquidity effect. Therefore, we can conclude that in the reference models, the liquidity effect of monetary policy dominates the loan demand effect and the anticipated inflation effect. To analyze now the full agency model with entrepreneurial cash holding, we have to take into account that in this model the substitution effect is working. As this effect increases the demand of loans, it in fact strengthens the loan demand effect and therefore the potential increase of the nominal interest rate of loans. As Figures 4 and 5 show respectively, the nominal interest rates increase in this model. For this reason we can conclude that the upward pressure on interest rates, exerted by the loan demand effect, the anticipated inflation effect, and the substitution effect, is strong enough to dominate and to lead to an increase of the nominal interest rate of loans.

To summarize, we can state that the positive impulse response of the nominal interest rates in the agency costs model with entrepreneurial cash holding is an outcome of the possibility of intertemporal substitution of entrepreneurial consumption. Therefore, modeling heterogeneous borrowers with different amounts of net worth implies in our model that the stylized fact concerning the interest rates is not reproduced any more.

Besides the change of the interest rate impulse, the model with heterogeneous borrowers has also an interesting effect on the general model dynamics. In the reference models, the decrease of the loan interest rate implies that labor costs and capital costs decrease as well, as firms have to borrow the factor payments for labor and capital. The decreased costs imply an increase in the demands for labor and capital on the part of the firm, which increases output. In the model with entrepreneurial cash holding the increased nominal loan interest rate rises factor costs and therefore leads to a potential decrease of factor demands. But in contrast to this argument, factor inputs increase as well. This is caused by the fact that the movements in the loan interest rate are now due to the changed loan demand and not due to a changed loan supply. So, borrowers are willing to borrow more money from the financial intermediary even if the interest rate is higher. This increased loan volume is then used for factor payments, so that also in this model, factor inputs and output increase.

Another interesting question is whether the consideration of endogenous borrowers' net worth produces amplification or stronger propagation, compared to models without endogenous net worth. To answer this question, we compare the impulse response functions of aggregate output for all three models, shown in Figure 2. We see that the output responses of both agency models, the one with endogenous net worth and the one with constant entrepreneurial cash holding, are almost identical. Both dampen the impulse response, compared to the standard monetary business cycle model. After the period of the shock, the responses of the three models then almost coincide. Therefore, modeling endogenous net worth neither produces amplification nor propagation.

4 Conclusion

This paper developed a model of the credit channel interpretation of the monetary transmission mechanism. In particular, important aspects were to endogenize the special role of the banking sector and to allow for heterogeneous net worth across borrowers. To realize this, a costly state verification framework was introduced into an otherwise standard monetary business cycle model. The informational asymmetry creates a moral hazard problem in lending. Agency costs are all encompassing in the sense that they arise in the production of aggregate output.

The model economy was calibrated to roughly match empirical counterparts and afterwards solved by the method of undetermined coefficients. Then the quantitative properties of the model economy were discussed by computing and analyzing the impulse responses of the system to a monetary shock. The numerical simulations showed two major points: First, the model with heterogeneous borrowers does not replicate as many stylized facts as the model without heterogeneous borrowers because the movements of the nominal interest rates cannot be reproduced any more. Second, the model dampens the impulse response of output after a positive money supply shock, compared to the standard monetary business cycle model. Therefore, the often quoted criticism that the dynamic stochastic general equilibrium business cycle model does not have a strong internal propagation mechanism is even strengthened in this framework.

Interestingly, the results of this paper differ from the results of Fachat (2000). There agency costs arise in the production of investment goods and not in the production of aggregate output. In Fachat (2000) it is shown that the important stylized facts of positive output and employment responses can only be reproduced in the model with endogenous net worth accumulation. The paper than concludes that "the agency-model with ex ante heterogeneous entrepreneurs represents a clear improvement to the standard monetary model as well as to the agency model with ex post heterogeneity only".

In this paper as well as in the accompaning paper Fachat (2000), it is shown that modeling endogenous net worth accumulation of borrowers alters the model dynamics. At least in Fachat (2000) we can see that these changes are clear improvements. But even if the model fails to reproduce one or more stylized facts, as it is the case for the model in this paper, it is important to allow for endogenous cash holding for several reasons: First, this is the only way to fully model the credit channel of the transmission mechanism of monetary policy. Second, without endogenous net worth, the important substitution effect of the entrepreneurs is neglected for the model dynamics. Third, net worth is empirically an important aspect which should also appear in theoretical models.[14]

In order to improve the replication of the stylized facts of monetary policy, several modifications can be done: A possible extension is to abandon the assumption that credit contracts can depend only on an entrepreneur's current level of net worth and not on his past history of debt repayments. This would allow for multi-period contracts which are, unfortunately, very difficult to handle in an infinite general equilibrium setting.[15] Alternatively, we could assume a different informational framework and leave the costly state verification setting with deterministic monitoring. With other informational settings or credit contractual arrangements we could perhaps solve the puzzle that the bankruptcy probability of entrepreneurs is identical whatever their net worth might be. Then, monetary policy would have different effects on the entrepreneurs, dependent on their individual probability of going bankrupt. This would probably improve the replication of the respective stylized facts.

Another possible extension of the model is to change the sector being subject to agency problems. In this chapter, agency costs arise in the production of aggregate output, whereas in Fachat (2000) these cost arise in the production of the investment goods. A third alternative is to construct a model in which agency costs arise in the relation between household and banking sector and therefore

[14]For the empirical importance see, e.g., Gertler and Gilchrist (1993), Gertler and Gilchrist (1994), and Oliner and Rudebusch (1996).

[15]For multi-period contract problems in other environments, see, e.g., Gertler (1992) or Townsend (1982).

abandon the assumption of a safe interest rate of deposits.

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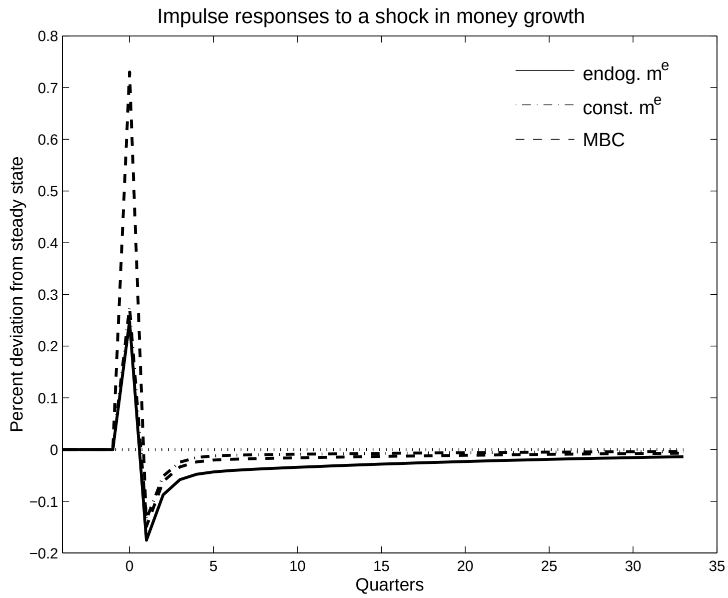

Figure 1: Labor

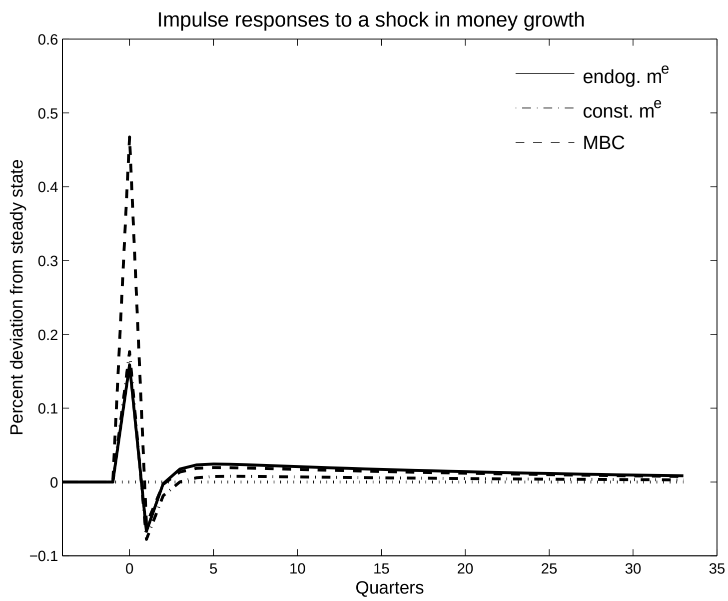

Figure 2: Output level

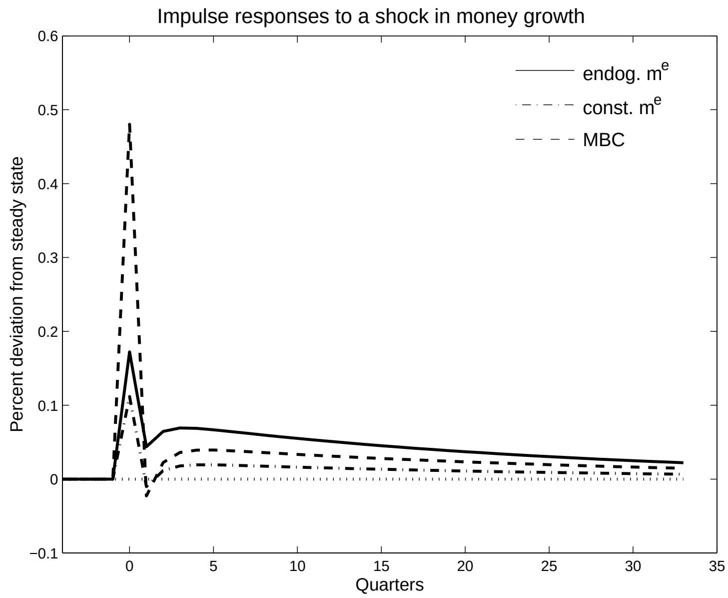

Figure 3: Real wage rate

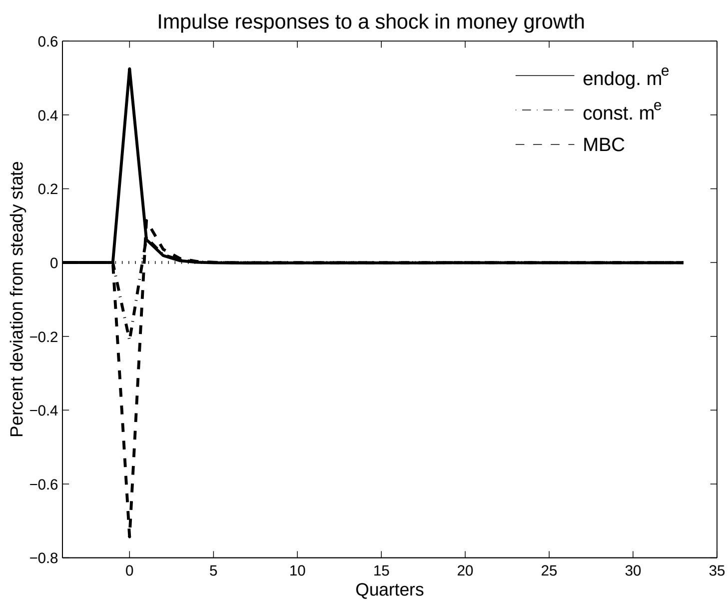

Figure 4: Interest rate of deposits

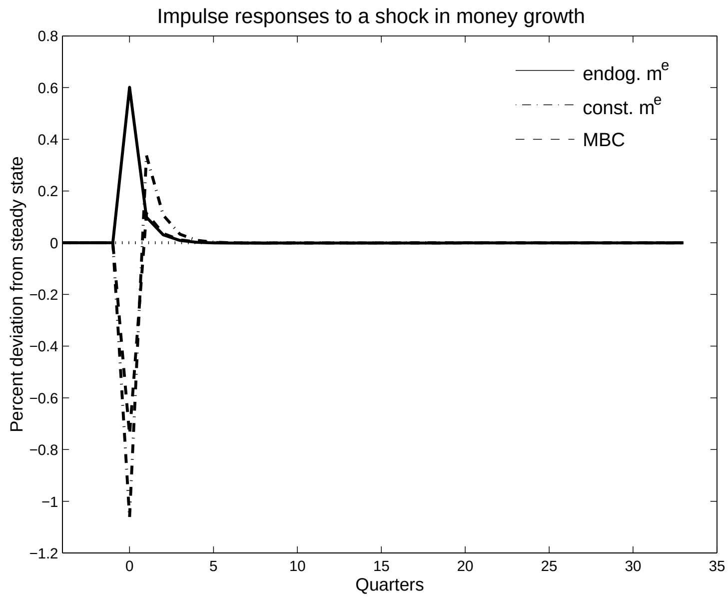

Figure 5: Interest rate of loans

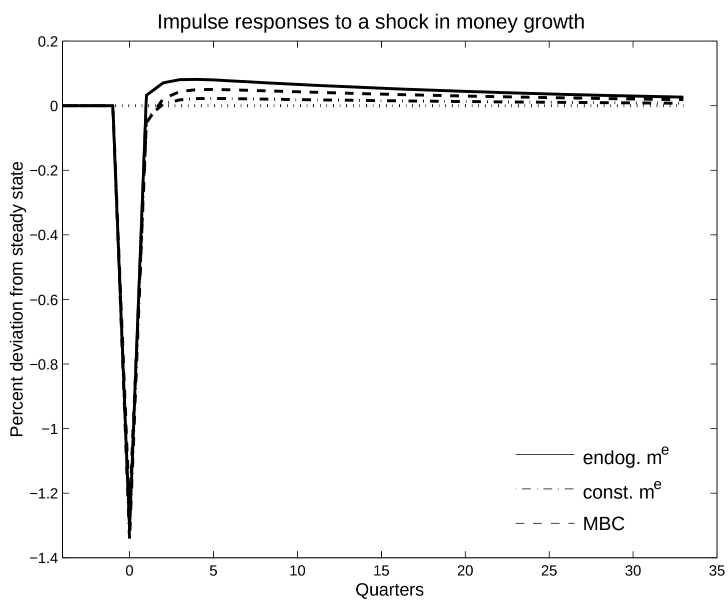

Figure 6: Household consumption

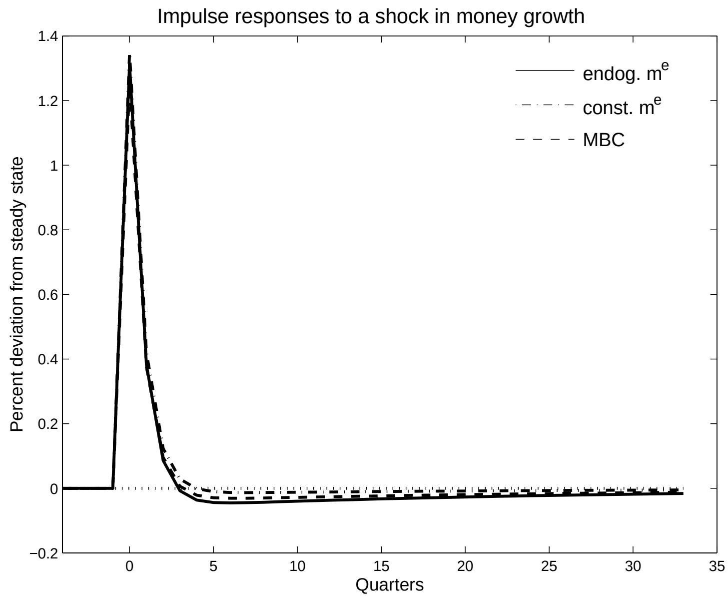

Figure 7: Output price level

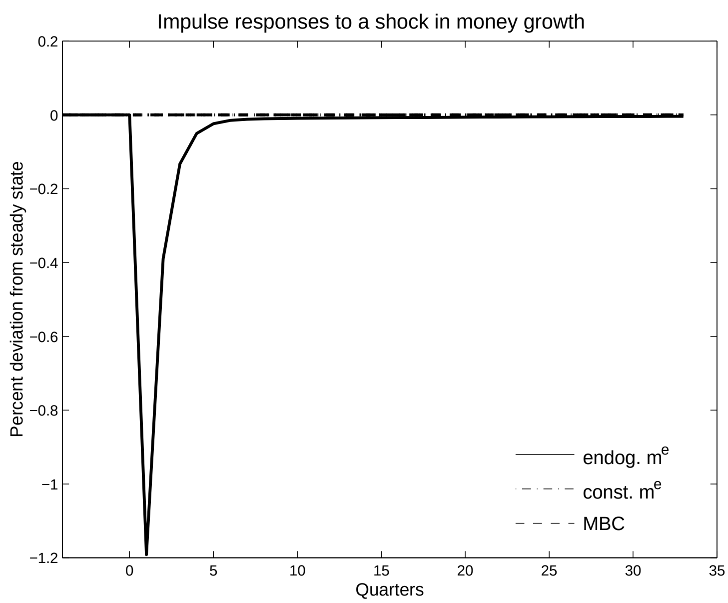

Figure 8: Entrepreneurial cash holding