BANKING AND INTEREST RATES IN MONETARY POLICY ANALYSIS:
A QUANTITATIVE EXPLORATION

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ABSTRACT

The paper reconsiders the role of money and banking in monetary policy analysis by including a banking sector and money in an optimizing model otherwise of a standard type. The model is implemented quantitatively, with a calibration based on U.S. data. It is reasonably successful in providing an endogenous explanation for substantial steady-state differentials between the interbank policy rate and (i) the collateralized loan rate, (ii) the uncollateralized loan rate, (iii) the T-bill rate, (iv) the net marginal product of capital, and (v) a pure intertemporal rate. We find a differential of over 3 % pa between (iii) and (iv), thereby contributing to resolution of the equity premium puzzle. Dynamic impulse response functions imply pro-or-counter-cyclical movements in an external finance premium that can be of quantitative significance. In addition, they suggest that a central bank that fails to recognize the distinction between interbank and other short rates could miss its appropriate settings by as much as 4% pa. Also, shocks to banking productivity or collateral effectiveness call for large responses in the policy rate.

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1. Introduction

Recent years have seen great changes in monetary policy analysis, as economists in central banks and academia have come together on an analytical approach of the general type discussed by Rotemberg and Woodford (1997), Goodfriend and King (1997), Clarida, Galí, and Gertler (1999), Woodford (2003), and many others. This approach is characterized, as argued by McCallum (2002), by investigations of alternative rules for monetary policy conducted in models that are based on private-agent optimizing behavior but with specifications that include features designed to lend empirical veracity, thereby aspiring to be structural and accordingly usable (in principle) for policy analysis. Despite a widespread belief that this approach is fundamentally sound, and that recent work represents a major improvement over the practice typical 15 or 20 years ago, there are some reasons for unease. Prominent among these are the absence from the standard framework of any significant role for monetary aggregates, financial intermediation, or distinctions among various short-term interest rates that play different roles in the transmission mechanism.

A recent paper by Goodfriend (2005) develops a qualitative framework designed to overcome these particular weaknesses. Specifically, it "… integrates broad money demand, loan production, asset pricing, and arbitrage between banking and asset markets" (2005, p. 277) and illustrates the logical necessity (in principle) for monetary policy to take account of—among other things—the difference between the interbank rate of interest (used as the policy instrument) and other short rates including the government bond rate, the collateralized bank loan rate, the (nominal) net marginal product of capital, and a shadow nominal intertemporal rate—each of which differs from the others. As noted by Hess (2005), however, Goodfriend (2005) provides no evidence or argument concerning the quantitative importance of these features and distinctions. The primary objective of the present paper, accordingly, is to formulate a quantitative version of Goodfriend's model, develop a plausible calibration, and utilize this model to assess the magnitude and policy

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relevance of the effects and distinctions just mentioned for steady state interest rates and aggregate variables, and for dynamic monetary policy simulations. Among other things, the paper will investigate the role of the "external finance premium" that is emphasized in the prominent work of Bernanke, Gertler, and Gilchrist (1999). It will do so using a model in which the external finance premium is endogenously determined by no-arbitrage relationships in an environment in which loan production depends upon both collateral and loan-monitoring inputs, with capital serving less efficiently as collateral than bonds, while bank-deposit money is crucial for facilitating transactions. In this setting, the external finance premium may move either pro-cyclically or counter-cyclically in response to shocks, depending upon parameters of the model.

How does the present paper compare with previous efforts to outline and quantify the role of financial intermediation (banking) in monetary policy? Probably the most prominent line of work of this type is that begun by Bernanke and Gertler (1989, 1995) and continued by Bernanke, Gertler, and Gilchrist (1999), but the literature also includes notable contributions by Kiyotaki and Moore (1997), Carlstrom and Fuerst (1997), Kocherlakota (2000), Cooley, Marimon, and Quadrini (2004), and others. It is apparently the case, however, that in all of these studies the models are fundamentally non-monetary—i.e., do not recognize the existence of a demand for money that serves to facilitate transactions.[1] This omission could be of first-order importance for the financial accelerator, however, for its mechanism works via increases in the supply of collateral induced by asset price increases. In models with money, however, such increases also increase the demand for collateral as spenders go to the banking system for additional money to facilitate the additional spending induced by the initiating shock. Accordingly, our analysis focuses on the net effect of these offsetting forces.

Our model's "banking accelerator" transmission effects work in much the same way as the

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[1] Diamond and Rajan (2006) is a noteworthy qualitative study of the role of banking in monetary policy.

financial accelerator does in existing models. For instance, monetary policy that stimulates employment and output in the presence of sticky prices raises the marginal product of capital, the price of capital, and the value of collateral in the economy, thereby tending to reduce the external finance premium for a given quantity of bank deposits demanded. However, our model includes in addition "banking attenuator" effects, which recognize that monetary stimulus to spending also increases the demand for bank deposits, thereby tending to raise the external finance premium for a given value of collateral-eligible assets in the economy.

Also of some indirect relevance to the present exploration are the studies of Ireland (2003), McCallum (2001), and Woodford (2003, pp. 300-311), which seek to quantify the effects of neglecting monetary aggregates in model specifications that do not adopt the usual approximation that is necessary to keep monetary aggregate magnitudes from appearing in the intertemporal optimizing conditions of a standard policy-analysis model. These papers, all of which found only small effects of this approximation, did not include any explicit banking sector, however, and did not recognize distinctions among various short-term interest rates.

In effect, ours is a two-sector model with a goods-producing sector and a banking sector. Goods are produced with capital and work effort as usual. The banking sector produces loans (and thus deposits) according to a production function with inputs of monitoring effort and collateral, the latter consisting of government bonds and capital (employed in the goods-producing sector) held by households. The distinctions among various interest rates arise in the model because loans and deposits are costly to produce, in the sense that they require work effort, while collateral services allow an economization of that effort. Hence, the total return on bonds (or capital) has an explicit pecuniary component and also an implicit liquidity service-yield component that reflects the collateral services that this asset provides. Portfolio balance requires risk-adjusted equality between the various assets' total returns. Thus the sum of pecuniary and service-yield returns must equal a

shadow total nominal risk-adjusted interest rate. However, the pecuniary bond rate is less than the net nominal marginal product of capital because bonds are more productive as collateral than capital. In equilibrium the interbank rate, which is the cost of loanable funds for a bank, is below the (uncollateralized) loan rate by the marginal cost of loan production. Finally, the loan market and the asset markets are linked by a no-arbitrage condition between the uncollateralized loan rate and the shadow total nominal rate.[2]

The strategy of the paper is two-fold. First, it is to use observed average historical values of interest rates and rate spreads, together with observations on banking and macroeconomic aggregates, to calibrate parameters by reference to steady-state equilibrium values for the model with realistic trend productivity growth in the production of goods and loans. Our aim in this regard is to determine the extent to which the introduction of money and banking into an otherwise standard growth model can account for observable interest rate differentials, and how much money and banking matters quantitatively (on average) for aggregates like the capital stock, employment, and output. In this regard, we develop the implications of money and banking with reference to the famous equity premium puzzle of Mehra and Prescott (1985), summarized by Campbell (1999) as the puzzle of "why the average real stock return is so high in relation to the short-term interest rate."

The second part of our strategy is to linearize the model around the calibrated steady state to explore how much the inclusion of money and banking matters quantitatively for an otherwise standard "new neoclassical synthesis" (aka, "new Keynesian") model of monetary policy. In particular, we wish to investigate quantitatively how much a central bank can be misled by relying on a new neoclassical synthesis (NNS) model without money and banking when managing its interbank-rate policy instrument.

We begin by illustrating the presence of the two effects or mechanisms—the accelerator and

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[2] Different financial assets play an important role in the model's transmission process, in a manner that is somewhat reminiscent of monetarist views summarized by Meltzer (1995).

the attenuator—by which money and banking influence the model economy's dynamics.[3] Next, we

illustrate the extent to which a central bank could misjudge its interbank rate response to a goods

productivity shock by not taking money and banking into account. Finally, we consider shocks

emanating from the banking sector itself—a shock to loan monitoring productivity and a shock to

effective collateral that is meant to represent widespread financial distress.

The paper's outline is as follows. In Section 2, we begin by building upon the specification

of the Goodfriend (2005) model and highlighting some of its features. Next, in Section 3 we

emphasize the various interest rates that appear in the model and the frictions that make them differ

from each other. Then in Sections 4, 5, and 6 we develop the steady state solution that forms the

basis for the linearized version of the model, which will be used in subsequent analysis, and discuss

the steady state calibration and some of the quantitative consequences of incorporating money and

banking. In Section 7 we complete the specification and linearization of our dynamic model.

Finally, in Section 8 we conduct various policy experiments to see how this model performs in

comparison to more standard specifications without any banking sector. Conclusions are briefly

outlined in Section 9.

2. Core Model Outline

The model that we will use to investigate these issues regarding the role of money and

banking needs to be specified at the level of preferences and technology, so as to be potentially

structural and invariant to policy specification. In order to keep the analysis as simple as possible,

we have specified the model in terms of an optimizing problem for a typical household, which not

only consumes a bundle of differentiated commodities, supplies labor, and saves but also produces

for sale a differentiated good and in addition operates a (competitive) banking firm. Thus the basic

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[3] In discussions of the monetary transmission process, it is common to find references to various transmission
"channels," and we are tempted to utilize this terminology. In general equilibrium analysis, however, the concept of a
transmission channel is usually ambiguous, since the behavior of all variables is interrelated and a change in a single
parameter may affect several marginal conditions. Consequently, we have made an effort to resist this temptation.

optimizing analysis is conducted in one step. It will take a bit of discussion, nevertheless, to describe the details of the typical household's decision problem. When that task is completed, we will specify that there are many households and aggregate by assuming that they are all similar and finding a symmetric equilibrium.

The typical household's objective function is to maximize, at time t = 0, the value of

$$(1) \qquad E_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(c_t) + (1-\phi) \log(1 - n_t^s - m_t^s)]$$

where c_t is consumption during period t of Dixit-Stiglitz consumption bundles and $(1 - n_t^s - m_t^s)$ is leisure in t, with n_t^s representing labor supplied to the production of goods (in the household firm or elsewhere) and m_t^s is labor likewise supplied to banking activities (to be described below). In the household's budget constraint, we must recognize that the household pays for its consumption expenditures with income from its production and sale of goods, net receipts from supplying labor, net sales of its financial assets,[4] and net sales of capital goods. (For simplicity, we are going to keep the aggregate stock of capital on a deterministic steady growth path—with a steady-state magnitude that is determined endogenously—but individual households can buy or sell capital goods so their market price is a variable.) The household has market power in the product that it supplies, with θ being its elasticity of demand, stemming from a value of θ for the elasticity of substitution in consumption in the usual Dixit-Stiglitz aggregator setup. Consequently, the household maximizes (1) subject to two constraints. The first is the budget constraint

$$(2) \qquad q_t(1-\delta)K_t + \frac{B_t}{P_t^A} + \frac{H_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s) + c_t^A \left(\frac{P_t}{P_t^A}\right)^{1-\theta}$$

$$-w_t(n_t + m_t) - \frac{H_t}{P_t^A} - tax_t - q_t K_{t+1} - \frac{B_{t+1}}{P_t^A(1+R_t^B)} - c_t = 0,$$

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[4] Its financial assets are high-powered money and one-period government bonds. Note that asset-liability positions between households and banks are netted out, a step that requires that banking firms possess no monopoly power.

and the second is the sales equals net production constraint needed to reflect monopolistic competition in the supply of the household's own produced good, namely,

(3) $K_t^{\eta}(A1_t n_t)^{1-\eta} - c_t^A (P_t / P_t^A)^{-\theta} = 0$.

Here the variables are as follows: q_t = real price of capital,[5] K_t = quantity of capital at start of t, B_{t+1} = nominal bonds held at end of t, P_t = price of household's produced good in t, P_t^A = consumption goods price index, n_t = labor demanded by household as producer, m_t = labor demanded by household's banking operation, w_t = real wage rate, H_t = nominal holdings of base money held at the end of t, tax_t = real lump-sum tax payments in t, and R_t^B = nominal interest rate on government bonds purchased in t and redeemed in t+1. The Lagrangian multiplier on (2) is denoted λ_t and for (3) it is ξ_t, with β^t inserted (in both cases) in the Lagrangian expression for each period to make the multipliers represent values as of the indicated period t, not the startup date 0. In (3), $A1_t$ is a shock to productivity in goods production, similar to a standard technology shock in the real-business-cycle literature, whose mean increases over time at the trend growth rate γ. The superscript A on any variable, it might be noted, indicates that the variable is an economy-wide measure that each individual household takes as given.

    In addition, the model includes one more constraint, which will build in most of our money-and-banking content. Since we require that the model must pertain to a monetary economy, we need to incorporate the transaction-facilitating properties of money—the medium of exchange—in some explicit manner.[6] The most concrete way possible is via a constraint requiring the household to pay for consumption spending during period t with money held in that period. Our specification will have the medium of exchange composed entirely of bank deposits, and will require that

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[5] The relative price in terms of consumption goods.
[6] In the present version of our model, we do not distinguish between transaction balances and time deposits at banks. Medium of exchange money is implicitly central to our analysis because it is by managing the aggregate quantity of reserves, which banks hold to facilitate transactions, that monetary policy affects interest rates.

consumption during t must be rigidly related to deposits held at the end of t. We assume that this constraint always binds, and as a consequence will require below that $c_t = V D_t / P_t^A$, where D_t is nominal deposits and V is the constant that reflects the assumed rigidity.[7]

In this context, we come to the banking sector. We write the simplest possible bank balance sheet, namely,

(4) $H_t + L_t = D_t$,

where H, L, and D are high-powered (base) money, loans to households, and deposits, respectively, for the typical bank.[8] Our transaction constraint is

(5) $c_t = \dfrac{V D_t}{P_t^A}$,

which, together with (4), implicitly represents a derived demand for high-powered (base) money. For reference below, we let rr be the bank's chosen ratio of H_t (which equals bank reserves at the central bank) to deposits, so from the balance sheet we have $rrD_t + L_t = D_t$ or $D_t = L_t/(1 - rr)$.

Finally, the analytical heart of the banking sector specification is a model of loan "production" or, more accurately, loan management. This crucial activity is conducted, we assume, by a combination of collateral and loan monitoring, the latter activity being performed by workers whose labor is supplied by households to the banking sector, as mentioned above. Specifically, we posit the following production function pertaining to the management of loans:

(6) $L_t / P_t^A = F(b_{t+1} + A3_t kq_t K_{t+1})^\alpha (A2_t m_t)^{1-\alpha}$ $0 < \alpha < 1$.

Here we have a Cobb-Douglas production function with factor inputs being labor m_t (for

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[7] This is not our favorite specification; we plan to loosen it in subsequent work. Given, however, that we are using this constraint—similar in spirit to a "cash in advance" constraint—it is necessary to incorporate some factor such as V to take account of the fact that the velocity of aggregate bank deposits is far less than 1.0 for quarterly time periods. We follow the usual convention of calibrating the model so that time periods represent quarters.
[8] Kashyap, Rajan, and Stein (2002) offer a microeconomic explanation of the synergy between deposit and loan provision in banking.

"monitoring") and collateral $b_{t+1} + A3_t kq_t K_{t+1}$, with $b_{t+1} = B_{t+1}/P_t^A(1+R_t^B)$.[9] In the latter

expression the effective amount of collateral possessed by a typical household depends upon,

among other things, the price of capital goods, q_t. The constant k, $0 < k < 1$, reflects the inferiority

of capital to bonds for collateral purposes, resulting because capital goods (unlike bonds) typically

require substantial monitoring to verify their physical condition and market value. The variables

$A2_t$ and $A3_t$ are shock terms, reflecting stochastic technology effects, analogous to $A1_t$ in the goods

production function included in (3). Here $A2_t$, like $A1_t$, has a trend growth rate of γ whereas $A3_t$ is

trendless.

With the model as specified, we derive first-order optimality conditions pertaining to the

choice variables m^s, m, n^s, n, K, P, and B,[10] and also define the variable[11]

(7) $\quad \Omega_t = \alpha c_t /(b_{t+1} + A3_t kq_t K_{t+1}).$

Then imposing symmetry and market clearing, and also constant aggregate capital, we obtain the

following conditions for equilibrium:

(8) $\quad \dfrac{1-\phi}{1-n_t - m_t} = w_t \lambda_t$

(9) $\quad w_t = \left(\dfrac{\phi}{c_t \lambda_t} - 1\right)\dfrac{(1-\alpha)c_t}{m_t}$

(10) $\quad w_t = (\xi_t/\lambda_t) A1_t (1-\eta)\left(\dfrac{K}{n_t A_{1t}}\right)^{\eta}$

(11) $\quad \left(\dfrac{\phi}{c_t \lambda_t} - 1\right) k\Omega_t q_t - q_t + \beta(1-\delta)E_t\left(\dfrac{\lambda_{t+1}}{\lambda_t} q_{t+1}\right) + \beta\eta E_t\left(\dfrac{\lambda_{t+1}\xi_{t+1}}{\lambda_t \lambda_{t+1}}\left(\dfrac{A1_{t+1} n_{t+1}}{K}\right)^{1-\eta}\right) = 0$

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[9] Banks expend effort and require borrowers to post collateral, but in equilibrium there is no default. This modeling choice is based, in part, on progress that has been made in understanding the implications of credit market imperfections in limited commitment environments where there is no equilibrium default, such as Kocherlakota (1996).
[10] The system has some recursivity such that c_t and H_t can be solved for after the other variables.
[11] The role of variable Ω_t will be described in Section 3.

(12) $\left(\dfrac{\phi}{c_t\lambda_t}-1\right)\Omega_t - 1 + \beta E_t\left(\dfrac{\lambda_{t+1}P_t}{\lambda_t P_{t+1}}\left(1+R_t^B\right)\right) = 0$

(13) $\xi_t/\lambda_t = (\theta-1)/\theta$

(14) $b_{t+1} = B_{t+1}/P_t^A(1+R_t^B)$.

(15) $g_t - \text{tax}_t = H_t/P_t^A - H_{t-1}/P_t^A + B_{t+1}/(1+R_{t+1}^B)P_t^A - B_t/P_t^A$

Here (15) is the government (including central bank) budget constraint. In a symmetric, flexible-price equilibrium, equations (2)-(15) serve to determine values of the fourteen endogenous variables c, n, m, w, q, P, λ, ξ, L, D, Ω, B, tax, and R^B given exogenous shock processes and policy-set time paths for H, g, and b.[12] Alternatively, and more realistically, we will also study equilibria in which the central bank sets values of an overnight interest rate, rather than H_t. In the foregoing list of variables, we have not included the capital stock, K, because our equilibria are defined with K_t equal to its steady-state value in each period. The steady-state value of K is, nevertheless, determined endogenously.

In our experiments involving dynamic adjustments we will utilize a sticky-price version of the model by eliminating the labor demand equation (10) and replacing it with a standard Calvo price adjustment relation, in a manner that will be described below in Section 5.

3. Interest Rates

Now we turn our attention to the various interest rates mentioned in the introduction. With the exception of the bond rate for loans to the government, these did not appear in the analysis of Section 2 because of our expositional strategy of treating goods producers and banks as owned and operated by households. Here we introduce a one-period default-free security that provides no collateral services to its holder and accordingly bears a shadow "total" return that represents a purely intertemporal rate of interest that the sum of risk-adjusted pecuniary and service yields on

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[12] For simplicity, we keep government spending g_t equal to zero throughout.

other assets must match. We denote the nominal rate on this fictitious security as R_t^T, as in Goodfriend (2005), and will use it as a "benchmark" rate in what follows. From the specification of the household optimization problem above, it can be seen that R_t^T must satisfy the familiar condition

(16) $1 + R_t^T = E_t \dfrac{\lambda_t P_{t+1}}{\beta \lambda_{t+1} P_t}$.

How does this rate relate to the bond rate that appeared above, R_t^B ? By comparison with first-order condition (12) for optimal household holdings of bonds, we see that

(17) $\dfrac{1 + R_t^B}{1 + R_t^T} = 1 - \left(\dfrac{\phi}{c_t \lambda_t} - 1 \right) \Omega_t$.

Thus these two rates coincide only if $\Omega_t = 0$ and/or $\phi / c_t \lambda_t - 1 = 0$. The former condition makes good intuitive sense, as $\Omega_t \geq 0$ can be viewed as the partial derivative of the constraint (5) with respect to collateral, so the rates can differ only if collateral services are valued at the margin. But with our production function in (6) and $0 < \alpha < 1$, both Ω_t and $\left(\dfrac{\phi}{c_t \lambda_t} - 1 \right)$ will be positive in all periods.

Therefore we can identify $\left(\dfrac{\phi}{c_t \lambda_t} - 1 \right) \Omega_t$ as the liquidity service yield on bonds, which we denote as LSY_t^B. From (17), then, we have the approximate equality

(18) $R_t^T - R_t^B = LSY_t^B$.

In our model's non-stochastic steady state, bonds and capital will have the same risk properties, but capital will serve as collateral less well than bills, by the factor k. Accordingly, one might guess that the liquidity service yield on capital, LSY_t^K, would satisfy the approximation

(19) $LSY_t^K = k \times LSY_t^B$.

In fact, that result can be verified by a more complex calculation analogous to the one for bonds.[13]

A crucial interest rate for monetary policy analysis is the interbank rate, denoted R_t^{IB}. Since such a rate serves as the policy rate for the Federal Reserve and many other central banks, R_t^{IB} will be viewed as the policy instrument in some of our experiments in Section 8. How, then, is the interbank rate R_t^{IB} related to other rates? The basic fact is that, in our model, a bank can obtain funds from the interbank market at the rate R_t^{IB} and could loan them to households, <u>if</u> it incurred all the necessary costs, at the benchmark rate R_t^T. This reflects a no-arbitrage condition between the loan market and the asset market. Then what are these costs? We have postulated above that loan production requires monitoring costs and collateral costs as specified in equation (6). Here we temporarily adopt the fiction that the collateral costs are borne by the bank, i.e., we consider uncollateralized loans. At the cost-minimizing optimum mix of factor inputs, the real marginal cost of loan production equals the factor price divided by that factor's marginal product for each factor of production. Thus we can find this marginal cost as the real wage divided by the partial derivative of L_t/P_t with respect to m_t, where the latter is employment of labor services (for monitoring) by the typical bank. From (6) we find this partial derivative to be $(1 - \alpha)(L_t/P_t)/m_t$ so using expression (4) we obtain $Vm_t w_t/(1-\alpha)(1-rr)c_t$ as the real marginal cost of loan management. Profit maximization by banks implies, then, that

$$(20) \quad (1 + R_t^{IB})\left[1 + \frac{Vw_t m_t}{(1-\alpha)(1-rr)c_t}\right] = (1 + R_t^T),$$

which can be approximated as

$$(21) \quad R_t^T - R_t^{IB} = \left[\frac{Vw_t m_t}{(1-\alpha)(1-rr)c_t}\right].$$

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[13] This result, and the one in the previous paragraph, is more fully developed in Goodfriend (2005).

Now, although we can imagine uncollateralized loans to households at the "total" asset

market rate R_t^T, actual loans are collateralized in equilibrium. Accordingly, since $(1 - \alpha)$ is the

factor share for monitoring, the marginal cost of loan production is multiplied by $(1 - \alpha)$ and the

relevant relationship becomes

$$(22) \quad (1 + R_t^{IB})\left[1 + \frac{Vw_t m_t}{(1 - rr)c_t}\right] = (1 + R_t^L),$$

where R_t^L is the interest rate on collateralized loans. As before, the corresponding approximation is

$$(23) \quad R_t^L - R_t^{IB} = \left[\frac{Vw_t m_t}{(1 - rr)c_t}\right].$$

Finally, in our setup, banks are paying households a rate R_t^D on their deposits. Given

competitive conditions, this rate differs from the interbank rate only because the fraction $1 - rr$ of

non-interest bearing deposits are not loaned, implying that

$$(24) \quad R_t^D = R_t^{IB}(1 - rr).$$

Given this plethora of interest rates and rate differentials, which differential is it that

measures the "external finance premium" in the context of our model? We identify the external

finance premium with the real marginal cost of loan production, since our loan production costs

reflect the cost of external finance emphasized by Bernanke, Gertler, and Gilchrist (1999), among

others. Household borrowers pay a loan rate that covers real marginal cost in addition to the

interbank rate, which equals the deposit rate except for a small discrepancy due to a non-zero (but

low) reserve ratio. Hence, the real marginal cost of loan production is an external finance premium

from the household's perspective.

It is useful to distinguish between an uncollateralized and a collateralized external finance

premium in our model. The external finance premium on an uncollateralized loan (UEFP) would be

$R_t^T - R_t^{IB}$ because this interest rate spread reflects the full real marginal cost of loan production. In effect, the uncollateralized loan rate is equated to R_t^T.

On the other hand, the spread between the collateralized loan rate and the interbank rate is $R_t^L - R_t^{IB} = (1 - \alpha)(R_t^T - R_t^{IB})$ because the smaller $R_t^L - R_t^{IB}$ interest rate spread need only cover the portion of real marginal loan cost due to the monitoring effort required when the borrower puts up the requisite collateral. In effect, households that borrow on a collateralized basis receive a deduction on the loan rate equal to the share α of collateral in loan costs. For calibration, we identify the collateralized external finance premium, which we denote as CEFP, with the spread between the prime rate and the interbank rate.

Because the banking sector is perfectly competitive and loan production features constant returns to scale, net interest income $(R_t^T - R_t^{IB})$ L_t/P_t equals the sum of payments to the factor inputs in loan production, $m_t w_t + b_{t+1} LSY_t^B + q_t(K_{t+1}) LSY_t^K$. The zero profit condition indicates that the liquidity service yields on bonds and capital can be interpreted as "rent" paid to borrowers for the collateral services that their assets provide in loan production. Bonds and capital earn lower pecuniary returns than R_t^T, the benchmark on a fictitious bond that provides no collateral services, by amounts equal to the "rent" that bonds and capital earn as deductions on borrowing costs. Drawing upon equations (19), (18), (9), and (23) above, it can be shown by succesive substitution that the external finance premium and the liquidity service yields on bonds and capital are related to each other as $LSY_t^K = k \times LSY_t^B = k \, \Omega_t \, [(1-rr)/V(1 - \alpha)] \, CEFP_t$.

4. Steady State Solution

The next step is to present the deterministic, zero-inflation, steady-state version of the model in Section 2 as a basis for calibration and our first batch of analytical exercises.[14] Preliminary

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[14] Henceforth, we will just say "steady state" rather than "deterministic, zero-inflation, steady state."

consideration of the steady-state system indicated that the inclusion of output growth would be essential to any degree whatsoever of realism. Accordingly, we assume that the shock terms $A1_t$ and $A2_t$ in the production functions for goods and loans each trend upward at the growth rate γ. Therefore, deterministic expressions for these two variables can be written as $A1_t = A_{10}(1 + \gamma)^t$ and $A2_t = A_{20}(1 + \gamma)^t$. For simplicity we normalize by setting $A_{10} = A_{20} = 1$. For a steady state, then, λ_t must shrink at the rate γ. Next we note that the relative price of capital will, in the steady state, equal 1, so that detrended average per-household capital K_t is an endogenous constant, K. Consequently, by substituting out certain variables we can express the core steady-state system in terms of seven equations involving only the seven variables c, m, n, w, λ, Ω, and K.[15] Here c, w, λ, and K are constant detrended values of the variables written above, which grow (or shrink) at the rate γ, while the others are constant without any detrending. We will include q in the expressions to reveal its importance in the system, but the reader should keep in mind that q = 1 in the steady state and that k is a parameter. As a piece of notation, we use boc to denote the constant steady-state value of bonds to consumption and assume that the fiscal authority behaves so as to stabilize boc at an exogenous, policy-determined value.

The first step is to substitute (6) into (5) and write the result as

$$(25) \quad 1 = \frac{VF}{(1-rr)}\left(boc + \frac{kqK}{c}\right)^{\alpha}\left(\frac{m}{c}\right)^{1-\alpha}.$$

Then equations (7) – (11) above can be represented as follows:

$$(26) \quad \Omega = \frac{\alpha}{boc + kqK/c}$$

$$(27) \quad \frac{1-\phi}{1-n-m} = w\lambda$$

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[15] In addition, the variable r, which denotes the before-depreciation marginal product of capital, could be obtained recursively after the other seven variables are determined from $r - \delta = (\eta(\theta-1)/\theta)(n/K)^{1-\eta}$.

(28) $\quad w = \left(\dfrac{\phi}{\lambda c} - 1 \right) \dfrac{(1-\alpha)c}{m}$

(29) $\quad w = \dfrac{(\theta-1)(1-\eta)}{\theta} \left(\dfrac{K}{n} \right)^{\eta}$

(30) $\quad \left(\dfrac{\phi}{c\lambda} - 1 \right) k\Omega - 1 + \dfrac{\beta}{1+\gamma} \left(1 - \delta + \dfrac{\eta(\theta-1)}{\theta}(K/n)^{\eta-1} \right) = 0$

Finally, we also have one relation that amounts to the overall resource constraint that incorporates equations (2), (3), and (15); it is as follows:

(31) $\quad 1 = (K/c)^{\eta}(n/c)^{1-\eta} - \delta K/c$.

Thus we have (25)-(31) as the seven equations that determine the steady-state values of c, m, n, w, λ, Ω, and K, these being the only relevant variables since boc and q are exogenous.

Given these core-model variables, and a given steady-state inflation rate, one can then readily solve for steady-state values of R^T, R^B, R^{IB}, R^L, and R^D using equations (16), (17), (21), (23), and (24). Accordingly, we now turn to our calibration.

5. Calibration

One leading objective in the paper is to explore the quantitative consequences of money and banking for interest rates and monetary policy in an otherwise conventional benchmark NNS model. Because the model in this paper is not as flexibly specified as we would like, our aims are fairly modest. First, we want to determine whether a steady-state calibration exists that fits the relevant observed variables tolerably well. Second, we want to explore under this calibration how much money and banking matters quantitatively for the various interest rates and the model's other endogenous macroeconomic variables.

The model has twelve parameters that need to be specified. Six of the parameters appear in the benchmark model without money and banking. For these we follow convention. First, we

calibrate $\phi = 0.4$ to yield roughly 1/3 of available time working in either goods production or banking. Second, we choose $\eta = 0.36$ to reflect relative shares of capital and labor in goods production. Third, we choose θ to yield a markup of 1.1. Fourth, we choose a conventional (quarterly) value of $\beta = 0.99$. Fifth, we set the quarterly depreciation rate $\delta = 0.025$. Sixth, we set $\gamma = 0.0050$ to correspond to 2% productivity growth per year.

We calibrate the fiscal policy parameter boc by using values of U.S. public debt held domestically by private entities, relative to GDP, as of the third quarter of 2005. The resulting figure is boc = 0.56.

That leaves five parameters relating to money and banking. First, we calibrate velocity as the ratio of U.S. GDP to M3 for the fourth quarter of 2005, implying that $V = 0.31$. Second, we set the reserve ratio at rr = 0.005, measured as the ratio of U.S. total bank reserves to M3 as of December 2005. Finally, we calibrate the remaining three banking parameters α, k, and F jointly to match, as best as we can, the following conditions: (i) a 1% per year average short-term real "riskless rate" that is typical in the finance literature, e.g. Campbell (1999, p. 1233), (ii) a 2% average collateralized external finance premium that is in line with the average spread of the prime rate over the federal funds rate in the postwar United States, and (iii) a share of total U.S. employment in depository credit intermediation as of August 2005 of 1.6% as reported by the Bureau of Labor Statistics. Accordingly, the three remaining parameters are calibrated as $\alpha = 0.65$, $F = 9.0$, and k = 0.2. The relatively low productivity of capital implied by the latter is consistent with the fact that banks specialize in information-intensive lending, as opposed to (e.g.) mortgage or auto lending in which collateral is more productive in defraying monitoring costs.

Our model of money, banking, and interest rate spreads is constructed on what we regard as a sensible theoretical foundation. It was at the start of the exercise not at all obvious that banking parameters in the context of the macro model could be found that would achieve a reasonable

calibration. Nevertheless, we shall see below that the calibration works tolerably well and in our view does provide a basis for judging the quantitative importance of money and banking in the steady state and in the dynamic analysis of monetary policy.

6. Steady-State Analysis

We begin the analysis of the steady state below by describing how well the benchmark calibration given in Section 5 is able to match the endogenous interest rates and aggregates to the respective observables. Then we illuminate the quantitative consequences of money and banking for the steady state in two ways.[16] First, we compute a counterfactual calibration by presuming that the banking sector is 10 times as efficient in loan production as in the benchmark calibration. We compare "highly efficient banking" and benchmark calibrations to show how much money and banking matters quantitatively. Second, we perform two experiments based on the benchmark calibration to illustrate the model's sensitivity to the debt to GDP ratio[17] and the velocity of aggregate bank deposits.

The steady-state values of the endogenous variables for the benchmark calibration are reported in the top panel of Table 1. Starting with the labor market variables, we see that total available working time is close to 1/3 as desired. Moreover, the ratio of time worked in banking to total work effort, $m/(n+m)$, is 1.9% under the benchmark calibration, not far from the 1.6% ratio in the U.S. economy. The steady-state capital/output ratio is 2.7 annualized, which is also in an acceptable range.

Turning to the interest rates, note that the steady state is computed at zero inflation so that we can interpret all the interest rates as "real" rates. To start, note that the rate of interest R^T on the benchmark fictitious security that provides no collateral services is exactly 6% per annum. This follows directly from the calibrated values of β and γ, together with log utility, which imply that R^T

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[16] Linguistically, we refer to "money and banking" in the singular, since it is the combination that is of importance.
[17] Our model does not feature Ricardian equivalence because of the collateral services provided by bonds.

$= \rho + \gamma$, where $\beta = 1/(1+\rho)$. Strictly speaking, the interbank rate R^{IB} and the government bond rate R^B are both short-term interest rates in the model, so they should both be near the 1% per annum (p.a.) average short-term rate. The calibration puts the interbank rate at 0.84% p.a., which is satisfactorily close to 1%. However, the government bond rate is 2.1% per year under the calibration, which is less satisfactory. That said, the two rates do straddle the 1% p.a. average short-term rate, and neither is too far from 1%. In addition, it is noteworthy that the average maturity of the stock of public debt outstanding used to calibrate the model is around 5 years. On this basis one might presume that R^B under the calibration is more representative of a 5-year bond rate than the short-term T-bill rate. Thus it is interesting to note that Campbell, Lo, and MacKinlay (1997, p. 415) report an average 5-year term premium of around 1.2% p.a. relative to the short rate, which happens to match closely the spread between R^B and R^{IB} in our calibrated steady state. Such evidence provides a plausible reason why R^B is elevated under our calibration, and suggests that it would be useful to modify the model to distinguish various maturities of government bonds outstanding in order to improve the calibration. Finally, the 2% p.a. collateralized external finance premium under the calibration lines up very well with the average spread between the prime rate and the interbank rate. This agreement reflects one aspect of our strategy of choosing banking parameters so as to approximate the three conditions mentioned above.

In order to illuminate the extent to which money and banking matters quantitatively, for steady-state interest rates and macroeconomic aggregates, consider a counterfactual calibration in which loan production is 10 times as efficient as in the benchmark calibration, implying that banking services are much less costly to produce. Specifically, let $F = 90$. The endogenous steady-state variables produced by this counterfactual calibration are shown in the bottom panel of Table 1, labeled "highly efficient banking." The striking feature of the resulting steady state is that all the interest rates converge to R^T, while the external finance premium and work in banking shrink so

much as to be reported as approximately zero—zero to four decimal places.

Interpreting this counterfactual as a steady state in which banking services are almost free, we can compare it to the benchmark steady state in order to determine how much money and banking matters quantitatively for the endogenous variables. By this comparison, money and banking appears to matter very much in a number of ways. Costly money and banking pushes short-term interest rates, R^B and R^{IB}, lower by about 4 and 5 percentage points p.a., respectively, than they would be otherwise in the steady state.[18] Money and banking does this by creating a return to collateral and a consequent liquidity-service yield that pushes R^B far below R^T, and by making external finance costly in terms of work effort thereby forcing R^{IB} far below R^T. Specifically, under the benchmark calibration, the presence of costly money and banking creates a LSY^B of 4% per annum and a real marginal cost of uncollateralized loan production of 5% per annum. Note also, that the calibration implies a ratio of the collateralized to the uncollateralized external finance premium of $(R^T - R^L)/(R^T - R^{IB}) = 1 - \alpha = 0.35$.

Money and banking has significant quantitative consequences for nonfinancial macro-economic aggregates, too. Thus the steady-state capital stock is 5.7% higher in the benchmark calibration than in the counterfactual "highly efficient banking" steady state.[19] The reason is as follows. The return R^T on the fictitious security that yields no collateral services is invariant to the efficiency of the banking system. Hence, the total net return to capital, which (abstracting from differential riskiness) must equal R^T, is invariant across steady states. At the benchmark calibration $LSY^K = kLSY^B = 0.2(0.04) = 0.008$, so the marginal product of capital net of depreciation must be 0.8 percentage points p.a. lower, thereby requiring a higher K/n ratio. The K/n ratios are 28.7 and

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[18] From the perspective of our paper, we would say that the low risk-free rate in Huggett (1993) is due to an implicit broad liquidity services yield on the risk-free asset in his model.
[19] The extra accumulation of capital in our model is related to that in Aiyagari (1994). We would say that the steady-state spread between the rate of time preference and the marginal product of capital in Aiyagari's model represents an implicit broad liquidity services yield on capital.

26.5 in the benchmark and highly efficient banking steady states, respectively. The capital stock, K, is 5.7% higher in the benchmark calibration in spite of the fact that work in goods production, n, is 2.5% lower. The net result is that consumption, c, is about 1% lower due to costly money and banking, and total work m + n is about 0.5% lower.

Why exactly does money and banking push the interbank rate R^{IB} down so far, according to the benchmark calibration? The reason is that households have an inelastic demand for aggregate bank deposits in the model which must be funded by borrowing from banks. A no-arbitrage condition keeps the uncollateralized loan rate equal to R^{T}. Banks must cover the marginal cost of loan production to willingly accommodate the demand for loans needed to fund the desired deposits. At a zero net interest margin, $R^{IB} = R^{T}$, a bank would rather lend funds in the interbank market (where the marginal lending cost is zero). An excess supply of interbank credit pushes R^{IB} down to the point where the net interest margin just covers the real marginal cost of loan production. At that point the interbank credit market, the loan market, and the deposit market all clear.

The steady-state implications of money and banking in the benchmark calibration can be appreciated from the perspective of financial economics with reference to the "equity premium puzzle," which asks why real stock returns average 6 percentage points per annum above real short-term interest rates, such as the federal funds rate or the 3-month T-bill rate.[20] We have seen above that the inclusion of money and banking implies a liquidity services yield that pushes R^{B} below R^{T} by about 4 percentage points p.a., and competitive banks that push R^{IB} more than 5 percentage points below R^{T}. However, according to the benchmark calibration the liquidity services yield on capital only pushes the net marginal product of capital 0.8 percentage points p.a. below R^{T} in the steady state. Thus, according to the benchmark calibration, money and banking push real interest

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[20] See, e.g., Campbell (1999, p. 1234).

rates down relative to the return to capital, which we identify with equity, by a net of 4.2 percentage points for R^{IB} and 3.2 percentage points for R^B. Thus, it would appear that considerations of the kind related to money and banking identified in our model make a quantitatively significant contribution to resolving the equity premium puzzle.[21]

Before moving on to Sections 7 and 8, where we discuss the implications of money and banking for monetary policy more comprehensively, we consider the consequences of money and banking for the "real neutral interbank interest rate" from a steady-state perspective. In monetary policy practice, the neutral interbank rate is the level of the interbank rate thought to be consistent with full employment, with the economy growing at trend, and with the price level stabilized on a path consistent with the central bank's inflation target. Within our model, the neutral interbank rate accordingly has a natural interpretation as the real interbank rate in the steady state. Here we describe the sensitivity of the steady-state interbank rate to the ratio of government bonds to GDP and to the velocity of aggregate bank deposits, to indicate the magnitude of variations that a central bank should expect in the neutral interbank rate, according to our model, in economies in which costly money and banking is a reality.

We find, first, that a ratio of government bonds to GDP (boc) 50% higher than in the benchmark calibration raises R^{IB} by 0.9 percentage points p.a., and a boc ratio 50% lower reduces R^{IB} by 1.2 percentage points p.a.[22] These R^{IB} changes reflect changes in the real marginal cost of loan production associated with the effect of different values of boc on the weighted value of collateral in the economy. Second, we find that velocity (V) 10% higher than in the benchmark calibration increases R^{IB} by 0.8 percentage points p.a. and velocity 10% lower reduces R^{IB} by 1 percentage point p.a. The interbank rate is sensitive to V because velocity governs the demand for

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[21] See Bansal and Coleman (1996) for an asset-pricing model that distinguishes between explicit pecuniary and implicit service yields in a study of the equity premium, but in a manner quite different than ours.
[22] We interpret this experiment as if the steady-state rate of inflation is high enough to keep R^{IB} above the zero bound.

bank deposits and the induced demand for bank loans to fund deposits.

7. Linearization

We now move on to the dynamic issues mentioned in the introduction. In that regard we need to complete the specification of our dynamic model, linearize it in a suitable manner, and calibrate the new components. The first step is to recognize the presence, irrelevant in steady-state analysis, of sluggish price adjustments. For that purpose we adopt the most nearly standard of all price-adjustment formulations, the discrete-time version of the Calvo (1983) mechanism. We recognize that there are grounds for objection to this specification, but as our model is strongly unorthodox in other ways, we consider it best to stay close to the mainstream with this component. Accordingly, we adopt the following price adjustment equation, applicable at the household level and also to the general price level for goods in a symmetric equilibrium:

(32) $\Delta p_t = \beta E_t \Delta p_{t+1} + \kappa mc_t + u_t$ $\kappa > 0.$

Here $p_t = \log P_t = \log P_t^A$ so Δp_t represents the inflation rate, while mc_t is the real marginal cost of goods production. With sticky prices, relation (13) above is replaced by

(33) $mc_t = \xi_t/\lambda_t,$

so marginal cost is not constant in this case. We have added two equations and only one variable (not counting p_t or its defining equation) so some relationship from Section 2 has to be eliminated. It is, naturally, the labor demand function (10), which represents behavior under full price flexibility. In the numerical results below, we set $\kappa = 0.05$, intended to represent a typical value in the recent literature.

The other major addition to the model of Section 2 is a specification of monetary policy behavior by the central bank. In the policy experiments below we will use two alternative types of policy rules. The first is a rule for setting the interbank interest rate, R_t^{IB}. Specifically, we adopt a rule of the general type made famous by Taylor (1993), allowing (as in most recent work) inclusion

of a lagged value of R_t^{IB} to reflect the prevalence of interest-rate smoothing by many central banks:

(34)　　$R_t^{IB} = (1-\mu_3)[\mu_0 + (1+\mu_1)\Delta p_t + \mu_2 mc_t] + \mu_3 R_{t-1}^{IB} + e_t$.

Here we have written the rule in a fashion that implicitly sets the central bank's target inflation rate, say π^*, equal to zero. With a Cobb-Douglas production function, mc_t serves as a measure of the output gap used by Taylor (1993).

　　　While (34) expresses monetary policy behavior in a rather realistic way, it will be useful for diagnostic purposes also to consider some policy experiments based on an alternative type of rule that depicts the central bank as controlling the growth rate of the stock of high-powered (base) money, H_t. Specifically, we will also report results based on the following monetary policy rule, in which $h_t = \log H_t$ and Δh_t is the growth rate of H_t:

(34')　　$\Delta h_t = \rho^H \Delta h_{t-1} + e_t^H$.

Here and in what follows, we use symbols with a "hat" to represent fractional deviations from steady-state values. Also, in (34') we have $0 < |\rho^H| < 1$ while e_t^H represents the random, unsystematic component of policy behavior. In our model, $\hat{H}_t$ is related to consumption and the price level by equations (4) and (5); the implied linearized relationship is

(35)　　$\hat{H}_t = \hat{c}_t + \hat{P}_t$.

　　　Equations (32), (33), (34) [or (34')], and (35) are combined with linearized versions of equations (4)-(15). Because we are using a symmetric equilibrium condition, the number of equations needed is smaller than in Section 2. Essential relationships are as follows:[23]

(36)　　$\hat{\lambda}_t + \hat{w}_t = \left(\dfrac{n}{1-n-m}\right)\hat{n}_t + \left(\dfrac{m}{1-n-m}\right)\hat{m}_t$

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[23] Here ai_t denotes the fractional deviation from trend for Ai_t, $i = 1, 2, 3$.

(37) $\quad \hat{w}_t + \hat{m}_t + \left(\dfrac{c(1-\alpha)}{mw} \right)\hat{c}_t + \left(1 + \dfrac{c(1-\alpha)}{mw} \right)\hat{\lambda}_t = 0$

(38) $\quad \hat{\Omega}_t = \left(\dfrac{kK/c}{b+(kK/c)} \right)(\hat{c}_t - \hat{q}_t - a3_t) - \left(\dfrac{b}{b+(kK/c)} \right)\hat{b}_t$, with $b = B/(P(1+R^B)c)$

(39) $\quad \hat{c}_t = \left(1 + \dfrac{\delta K}{c} \right)(1-\eta)(\hat{n}_t + a1_t) - \left(\dfrac{\delta K}{c} \right)\hat{q}_t$

(40) $\quad \hat{c}_t = (1-\alpha)(a2_t + \hat{m}_t) + \left(\dfrac{\alpha bc}{bc + kK(1+\gamma)} \right)(\hat{b}_t + \hat{c}_t) + \left(\dfrac{\alpha kK(1+\gamma)}{bc + kK(1+\gamma)} \right)(a3_t + \hat{q}_t)$

(41) $\quad \hat{mc}_t = \hat{n}_t + \hat{w}_t - \hat{c}_t$

(42) $\quad \Delta \hat{p}_t = \hat{P}_t - \hat{P}_{t-1}$

(43) $\quad \left(\dfrac{k\Omega\phi}{c\lambda} \right)\hat{c}_t =$

$k\Omega \left(\dfrac{\phi}{c\lambda} - 1 \right)(\hat{\Omega}_t + a3_t) + \left[k\Omega \left(\dfrac{\phi}{c\lambda} - 1 \right) - 1 \right]\hat{q}_t + \dfrac{\beta}{1+\gamma}\left[1 - \delta + \eta mc(n/K)^{1-\eta} \right]E_t\hat{\lambda}_{t+1} + \dfrac{\beta}{1+\gamma}(1-\delta)E_t\hat{q}_{t+1}$

$+ \left[\dfrac{\beta\eta mc}{1+\gamma}(n/K)^{1-\eta} \right]E_t \left(\hat{mc}_{t+1} + (1-\eta)(\hat{n}_{t+1} + a1_{t+1}) \right) - \left[\dfrac{k\Omega\phi}{c\lambda} + \dfrac{\beta}{1+\gamma}(1-\delta+\eta mc(n/K)^{1-\eta}) \right]\hat{\lambda}_t$

The last of these, which is the linearized version of the first order condition with respect to the capital stock, is obviously a complex condition. Be that as it may, inspection of equations (32), (33), and (35)-(43) shows that the endogenous variables that appear in this system are $\Delta\hat{p}_t$, $\hat{mc}_t$, $\hat{\Omega}_t$, $\hat{\lambda}_t$, $\hat{\xi}_t$, $\hat{w}_t$, $\hat{n}_t$, $\hat{m}_t$, $\hat{c}_t$, $\hat{q}_t$, and $\hat{P}_t$. Thus, with policy determination of the paths of $\hat{H}_t$ and $\hat{b}_t$ we have the proper number of relationships for this essential set of variables.[24] Once their solutions are found, it is tedious but conceptually straightforward to calculate the interest rates R_t^T, R_t^B, R_t^{IB}, and R_t^L using linearized versions of the relationships (16), (17), (21), and (22) given in Section 3.

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[24] Of course, the dynamic solution requires proper attention to transversality conditions, etc. In all the results reported below, the utilized solution is the only stable solution.

8. Dynamic Analysis

Here we study dynamics using the linearized model calibrated at the steady state, as amended in Section 7 to include Calvo-style staggered pricing and a policy rule, to explore how much costly money and banking matters quantitatively for an otherwise standard NNS model of monetary policy. In our exercises, the dynamic consequences of money and banking for monetary policy are illustrated in two ways. First, we demonstrate the presence of two conflicting effects by which money and banking affect the transmission of monetary policy. We identify a banking "attenuator" effect that tends to blunt the impact of monetary policy actions. However, there is also a banking "accelerator" in the model, resembling the familiar financial accelerator, with the potential to amplify the impact of monetary policy actions. We discuss the mechanics and implications of the two potentially conflicting aspects of monetary transmission for the behavior of the economy and the effectiveness of monetary policy.

Second, we illustrate how much a central bank could be misled quantitatively in its interbank-rate policy actions by ignoring money and banking altogether. To this end, we investigate the extent to which a central bank could misjudge its interest rate policy response to a generic goods productivity shock by not taking into account the existence of money and banking. Then we consider two shocks emanating from the banking sector itself (which have no counterpart in the benchmark NNS model): a shock to loan monitoring productivity and a shock to effective collateral. The latter is meant to capture the effects of widespread financial distress.

The banking attenuator and accelerator effects are highlighted, respectively, in Figures 1 and 2. Each figure reports impulse responses of key endogenous variables to a 1 percentage point shock to policy rule (34') assumed to generate the growth of high-powered money. The experiments depicted in the two figures differ only in the assumed autoregressive (AR) coefficient of the money growth rule. Specifically, Figure 1 reports outcomes for a modest degree of money growth

persistence, with AR coefficient $\rho^H = 0.6$, whereas money growth in Figure 2 is highly persistent with $\rho^H = 0.99$.

In Figure 1, the modest degree of money growth persistence stimulates a 0.6 percentage point increase in consumption on impact that dies away relatively quickly as firms adjust prices to neutralize the cumulative money growth effect on the markup and, thereby, on other real variables. The aggregate demand stimulated by expansionary monetary policy is accommodated by an expansion of hours worked in goods production and an elevated real wage. There is also a relatively large increase in the real price of capital, q, due to the depressed capital-labor ratio and the elevated marginal product of capital.

The banking attenuator is evident in Figure 1 in the following sense. According to the broad liquidity constraint (25), the increase in consumption generates a proportionate increase in the demand for bank deposits that must be accommodated by a commensurate increase in loan production. The increase in the value of the capital stock associated with the rise in q provides additional collateral value that helps produce more loans. However, as revealed by the simulation, the banking system also expands loan production effort, m, to accommodate the increased demand for deposits and loans.

Figure 1 shows that the net effect, summarized in (21) and (23), of m, w, and c is to *raise* the external finance premium EFP temporarily by around 0.8 percentage points. The plot in Figure 1 pertains to both collateralized and uncollateralized versions of the EFP because linearized versions of both (21) and (23) give $EFP_t = \hat{m}_t + \hat{w}_t - \hat{c}_t$ with hatted values being fractional deviations from steady state. We see that R^{IB} initially rises but by less than R^T so the $R^T - R^{IB}$ interest rate spread rises at its peak by 0.8 percentage points. Both nominal interest rates rise initially, reflecting inflation expectations, but R^{IB} by less. R^T first rises and then falls relative to expected inflation due

to movements in the pure real rate of interest associated with the expected change in λ according to (16). Consequently, R^{IB} itself falls after one period by about 0.6 percentage points on net.[25]

In this case the external finance premium is procyclical—it rises in response to an expansionary monetary policy shock along with the real marginal cost of loans. If the model were to allow for investment financed externally at the margin, the procyclical external finance premium would attenuate the effect of monetary stimulus on investment. As it stands, a net attenuation is present in the model because effort is drawn into banking with the expansion of goods production. The procyclical effect on the external finance premium reflects the fact that monetary stimulus on consumption is accompanied by an increased demand for banking services to accommodate the demand for bank deposits. The net effect depicted in Figure 1 contrasts with the countercyclical finding in the work of Bernanke, Gertler and Gilchrist (1999), among others, in part because they neglect the direct relationship between consumption and the demand for bank deposits through the demand for money.

Figure 2 reports the results of a highly-persistent money growth shock that generates a highly persistent 1 percent rate of inflation, nearly twice the peak response of inflation in Figure 1. The higher rate of inflation in this case neutralizes much of the impact on consumption, which now rises by only 0.1 percent before it begins to fall. Hours worked in goods production and the real wage peak after a lag at only 0.2 percent above the steady state, respectively. However, the q price of capital still rises by around 0.4 percent and remains persistently elevated. The increased value of capital collateral *relative to consumption* allows broad liquidity constraint (25) to be satisfied with a substantial decline of nearly 0.5 percent of hours worked in banking.

Figure 2 shows that the net effect, according to (23), of m, w, and c is to *lower* the external finance premium persistently by as much 0.4 percentage points. R^{IB} rises by 1.4 percentage points

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[25] The reported decline in R^{IB} is relative to the steady-state. We interpret this simulation under the condition that the steady-state rate of inflation is sufficiently positive that R^{IB} remains above the zero bound.

on impact reflecting the sum of inflation expectations and the countercyclical external finance premium. The banking "accelerator" effect on monetary stimulus in this case reflects the fact that the banking sector requires less work effort to satisfy the increased demand for bank deposits, so that the real marginal cost of loan production falls. The present discounted value of the persistently elevated future marginal product of capital keeps the q price of capital high enough on impact to overcome the presence of the banking attenuator and support a net banking accelerator.

The mechanics of the banking accelerator are much the same as in Bernanke, Gertler, and Gilchrist (1999), and others, where a countercyclical external finance premium amplifies and propagates monetary policy shocks through a positive feedback loop that involves the monetary stimulus, asset returns, the q price of capital, and the consumption value of loan collateral. The difference is that in our model the accelerator effects are overridden by the attenuator in the case at hand. As currently specified, our model is perhaps unduly favorable to the attenuator in that all output is consumed and the velocity of bank deposits with respect to consumption is assumed constant. Realistic modifications of the model—allowing output to be invested and the velocity of deposits to vary—could shift the balance considerably.

We now proceed to ask: How much could a central bank that ignores money and banking misjudge the proper interest rate policy action to stabilize inflation in response to a goods productivity shock? We answer by comparing the responses of the real natural interbank rate of interest to a goods productivity shock in the model with and without money and banking. We do this by utilizing interest rate policy rule (34) with $\mu_1 = 50$, $\mu_2 = 0$, and $\mu_3 = 0$. With its strong response to inflation, this specification keeps inflation approximately equal to zero, which, given (32), stabilizes real marginal cost mc of goods production at its steady-state value. Thus, this specification of the interest rate rule essentially makes nominal interest rates behave like real natural

interest rates consistent with the underlying imperfectly competitive real business cycle model with flexible prices and a constant profit-maximizing markup.

In this context, we introduce a 1 percent shock to a highly-persistent first-order autoregressive goods productivity process with AR coefficient 0.99. The impulse responses shown in Figure 3 indicate that the following endogenous variables are nearly invariant to the shock: n, dp, R^T, and R^B. The model has log utility and non-storable output, so we would expect hours worked in goods production to be relatively insensitive to the highly-persistent shock to the level of productivity in goods production. The inflation rate is essentially stabilized, as is the benchmark nominal interest rate R^T according to (16), because expected inflation and the expected change in λ are approximately zero. The relative stability of R^T reflects the fact that desired household saving is relatively insensitive to the highly persistent shock to the level of productivity.

The striking contrast is that c, w, q, m, and the external finance premium all rise persistently by 0.6 or 0.7 percent. Why? With hours in goods production relatively stable, increased productivity shows up as a percent jump in consumption approximately equal to labor's share. The jump in the wage reflects the increase in labor productivity. And the q price of capital reflects the highly persistent increase in the marginal product of capital. The increase in banking hours reflects the increased demand for deposits associated with the rise in consumption via the linearized broad liquidity constraint (40). The small decrease in hours worked in goods production partly reflects the increase in banking hours. As a result, the external finance premium jumps by 0.6 percentage points.

These results reveal a striking quantitative effect of the presence of money and banking in the model. A central bank unaware of the effect of money and banking on interest rate spreads in general and on the interbank rate in particular would expect all real natural interest rates to behave like R^T. Hence, a central bank determined to make its interbank rate policy instrument shadow

movements in the real natural rate, so as to stabilize inflation perfectly, would move its interbank rate relatively little in response to a highly persistent productivity shock. Yet, the model with money and banking requires the central bank to cut its interbank rate by around 0.6 percentage points to stabilize inflation fully in response to such a shock. That amounts to a 2.4 annualized percentage point misjudgment of the desired interbank rate policy action.

What if the central bank followed a version of the Taylor rule without smoothing? To find out, we compute impulse responses to a 1 percent positive goods productivity shock with AR coefficient 0.99, but with interest rate rule (34) calibrated as $\mu_1 = 1.5$, $\mu_2 = 0.5$, and $\mu_3 = 0$. The striking result reported in Figure 4 is that this rule permits 2 percent deflation that is highly protracted! The deflation is associated with a persistent decline in real marginal cost (an elevated markup) in goods production. Expected deflation pushes all three nominal interest rates sharply lower. Hours in goods production, consumption, the wage, and the price of capital are all marginally lower than in Figure 3. The key banking variables, monitoring effort and the external finance premium, are both persistently higher under the specified rule.

Inclusion of money and banking, then, makes this version of the Taylor rule deflationary. If money and banking was costless, then there would be a single interest rate in the model, R^T. And the associated real interest rate would move little in response to the highly persistent goods productivity shock. (The permanent income theory of consumption says that aggregate demand would increase to absorb most of the increase in aggregate supply without much variation in the real interest rate.) Hence, the output gap would be small, and deflation could be averted with a relatively small cut in the interest rate.

According to our calibration, however, the real interbank rate must fall significantly relative to the real benchmark rate, R^T. However, the Taylor rule says that the real interbank rate cannot fall if inflation and the output gap are stabilized. Hence, in dynamic equilibrium the economy must

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settle at a point where there is just enough of an output gap and deflation for the Taylor rule to induce a cut in the real interbank rate to satisfy equilibrium in the banking sector. Thus, our model of money and banking suggests the existence of a quantitatively significant problem for plausible versions of the Taylor rule.[26]

Our remaining examples of the quantitative consequences of money and banking involve two shocks that emanate from the banking sector itself and thus have no counterpart in the usual NNS model: a shock to the productivity of monitoring effort and a shock to effective collateral.

The detrended productivity of monitoring effort in banking is represented by $a2_t$ in the linearized broad liquidity constraint (40), and is determined exogenously by a first-order AR process. We assume an AR coefficient of 0.99 for the banking productivity shock to capture the near-permanent nature of surprising improvements or disappointments in technological progress in banking. Assuming the same specification as in Figure 3 for the interest rate rule employed to stabilize inflation fully, Figure 5 displays impulse responses to a one percent banking productivity shock. As expected, the inflation rate is stabilized reasonably well, as are R^T and R^{IB}. Hours worked in banking falls by 0.85 percent in response to improved productivity in banking. There is little change in the q value of collateral, and therefore little effect on the supply of loans for given hours worked in banking. The fall in m, together with the negligible change in the wage and the small increase in consumption, produces a 0.9 percentage point fall in the external finance premium, which is reflected in an equivalent rise in R^{IB}. This means that a 1 percent improvement in banking technology requires the central bank to raise its real interbank rate policy instrument by 3.6 percentage points at an annual rate to stabilize inflation.

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[26] In this regard, the potential for large mistaken interbank rate policy actions might be reduced if the model were modified to allow banks to acquire government bonds as assets. As currently specified, banks do not borrow in the interbank market in order to hold government bonds outright. Since a bank would incur little loan production costs on either side of this arbitrage, a bank could profit by utilizing funds borrowed in the interbank market to buy government bills as long as R^B exceeded R^{IB}.

Here again money and banking potentially matter a great deal quantitatively for interest rate policy. A central bank unaware of the consequences of money and banking that wished to shadow the natural real interbank rate to stabilize inflation would miss completely the need to raise its interbank rate instrument to do so. The central bank would be surprised at the resulting strength of economic activity and inflationary pressure. Impulse responses not reported here show that a central bank following the Taylor rule of Figure 4 would in this case create inflation persistently in excess of 0.5 percent.[27]

For our last experiment we consider a shock meant to capture the consequences of financial distress that weakens a borrower's property rights to his capital, thereby making capital less productive in securing and producing loans. We model financial distress as a shock to k in (6), which shows up as a shock to $a3_t$ in the linearized equations (38) and (40). We assume that $a3_t$ is generated as an exogenous first-order AR process with AR coefficient of 0.9 to reflect modest persistence associated with resolving financial distress. Again, we specify the interest rate rule as above to stabilize inflation fully in order to illustrate the effect of financial distress on the natural interbank rate of interest.

Figure 6 displays impulse responses to a 1 percent negative shock to effective collateral. The inflation rate is stabilized reasonably well, as are R^T and R^B. Hours worked in banking rise by 1.2 percent in response to the decline in effective collateral. This rise in m, together with the implied small changes in c and w, produces a 1.2 percentage point rise in the external finance premium, reflected in an equivalent fall in the natural real interbank interest rate.

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[27] Again, there are reasons why shocks to banking technology need not precipitate such large movements in the natural interbank rate. First, the natural interbank rate is invariant to productivity shocks when banking and goods productivity trend upward together as in the steady state. Second, the variance of detrended banking productivity shocks that move independently of goods productivity shocks might be relatively small, with modest implications for the natural interbank rate. Third, if banks were allowed to hold government securities outright in the model, then arbitrage between R^{IB} and R^B would induce banks to sell government securities in response to the positive banking productivity shock, which would mitigate the rise in the natural interbank rate.

Once more, developments relating to money and banking potentially matter a great deal for interest rate policy. In this case, it is implausible that a central bank would remain unaware of the money and banking shock. Evidence of financial distress would be directly observable and reported in the media. Central banks generally recognize the need to cut the interbank rate in response to widespread financial distress. But, given the absence of money and banking in models of monetary policy, there is no way to judge how much to cut the interbank interest rate.

The simulation indicates that a 1 percentage point decline in effective collateral would require an initial 4.8 annualized percentage point cut in the interbank interest rate followed by a gradual return to neutral. This sensitivity of the natural interbank rate to widespread financial distress seems large in the sense that central banks rarely make such immediate, deep cuts in the interbank rate, even in response to a financial crisis.

To get a more realistic idea of the effect of financial distress, we consider a more realistic interest rate rule in Figure 7. Figure 7 displays impulse responses to the negative collateral shock when monetary policy is governed by a specification of interest rate policy (34) reflective of a Taylor rule with a lagged interest rate: $\mu_1 = 1.5$, $\mu_2 = 0.5$, and $\mu_3 = 0.8$. In this case, interest rate smoothing delays the cut in the interbank rate, which reaches a trough after about one year only 2.5 percentage points p.a. below neutral. Realistic interest rate policy produces more realistic macroeconomic outcomes: there is a recession with a 2 percent contraction in hours worked and a 2 percent per annum deflation. From this perspective, the sensitivity of the natural real interbank rate to the effective collateral shock evident in the simulation may not be implausibly large.

In fact, financial distress is likely to be accompanied by a flight to safety resulting in an increased demand for bank deposits relative to consumption. The decline in velocity would cause an even larger fall in the natural interbank rate than in Figure 6. On the other hand, if banks were allowed to hold government securities outright in the model, then arbitrage between R^{IB} and R^B

would induce banks to buy government securities in response to the financial distress. Such arbitrage would bring down R^B and R^T, cushion the decline in R^{IB}, and improve the capacity of the model economy to respond to financial distress.[28]

9. Conclusions

We conclude with a brief summary of the paper's scope and findings. Our objective was to reconsider the role of money and banking in monetary policy analysis by means of an analytical framework that includes both a banking sector and transaction-facilitating money in an optimizing model that is otherwise of the standard new neoclassical synthesis type. The addition of the banking sector leads to several unusual features, including a number of distinct interest rates. The model is implemented quantitatively, based on a calibration that attempts (within specificational constraints) to be realistic for an economy such as that of the United States.

Results obtained are of two types, pertaining to steady-state and dynamic properties of the model. In the former case we are reasonably successful in providing an endogenous explanation for substantial steady-state differentials between the short-term interbank interest rate, typically employed as the central bank's policy instrument, and the following: (i) the collateralized loan rate, (ii) the uncollateralized loan rate, (iii) the one-period government bond rate, (iv) the net marginal product of capital, and (v) a shadow nominal purely intertemporal rate, i.e., our "benchmark" rate. One steady-state experiment involves a counterfactual calibration that makes banking services almost costless to produce; this scenario results in interbank and bond rates that are 4 percentage points per annum higher than with our baseline calibration, thereby indicating a major quantitative effect of a banking sector. Effects on the steady-state capital stock are also sizeable; with costless banking services, the capital stock is over 5 percent lower than in the baseline calibration. Among other results, in the baseline calibration we find a differential of over 3 percentage points per annum

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[28] In this context, footnotes 25 and 26 are relevant.

between short-term interest rates and the return to capital, a magnitude that may contribute significantly to resolving the famous "equity premium puzzle." Finally, we report experiments with the baseline calibration that indicate a sizable sensitivity of the steady-state "neutral" interbank rate to the debt to GDP ratio and to the velocity of aggregate bank deposits.

Dynamic results are based on impulse response functions implied by a linearized version of the model. Here we demonstrate the quantitative significance of a "banking attenuator" effect that works in the opposite direction from the "financial accelerator" effects emphasized by Bernanke, Gertler, and Gilchrist (1999)—although these effects are also present in the model.

One of the more significant findings in this dynamic context is that, according to the model, a central bank that based its rate-setting policy on analysis that failed to recognize the distinction between the interbank rate and the benchmark intertemporal rate could miss its appropriate settings by as much as 4 percentage points. For instance, we show that a central bank that utilized an interbank interest rate instrument, with parameters chosen to represent a moderate version of the Taylor (1993) rule, would produce a persistent 2 percent per annum deflation in response to a 1 percent, highly-persistent positive shock to productivity in goods production.

Finally, we demonstrate the quantitative consequences of two shocks emanating from the banking sector itself: a shock to banking productivity and a shock to effective collateral reflecting financial distress. For instance, we indicate that the central bank would need to cut the real interbank rate initially by nearly 5 percentage points per annum to fully stabilize inflation and output against a moderately persistent, 1 percent decline in effective collateral. Moreover, we show that a more realistic policy response reflecting instead a Taylor-style rule with interest rate smoothing fails to offset the contractionary consequences of financial distress, instead permitting a recession with 2 percent per annum deflation and a 2 percent contraction in employment. In short, in our calibrated model, the effects of money and banking are quantitatively of major importance.

Table 1: Steady-State Calibrations

Benchmark Calibration
(quarterly data; zero inflation)

c	m	n	w	λ	Ω	K
0.8409	0.0063	0.3195	1.949	0.457	0.237	9.19

R^T	R^{IB}	R^L	R^B	CEFP
0.015	0.0021	0.0066	0.0052	0.0045

Highly Efficient Banking
(Same calibration as above except F = 90.)

c	m	n	w	λ	Ω	K
0.8490	0.000	0.3276	1.894	0.471	0.249	8.69

R^T	R^{IB}	R^L	R^B	CEFP
0.015	0.015	0.015	0.015	0.00
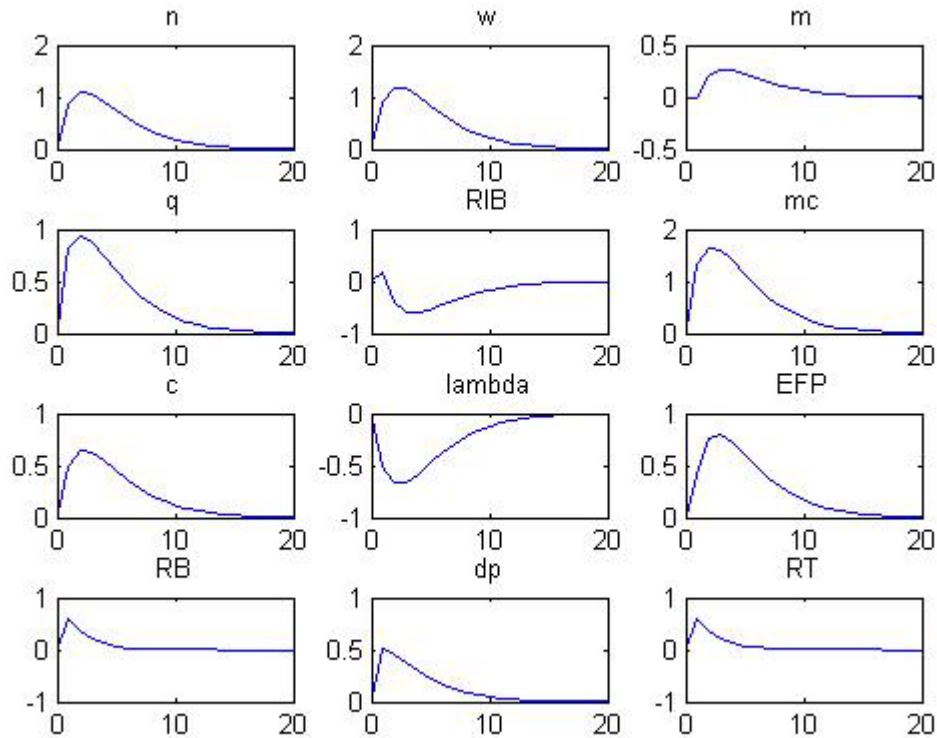
Fig. 1: Responses to unit shock to edh
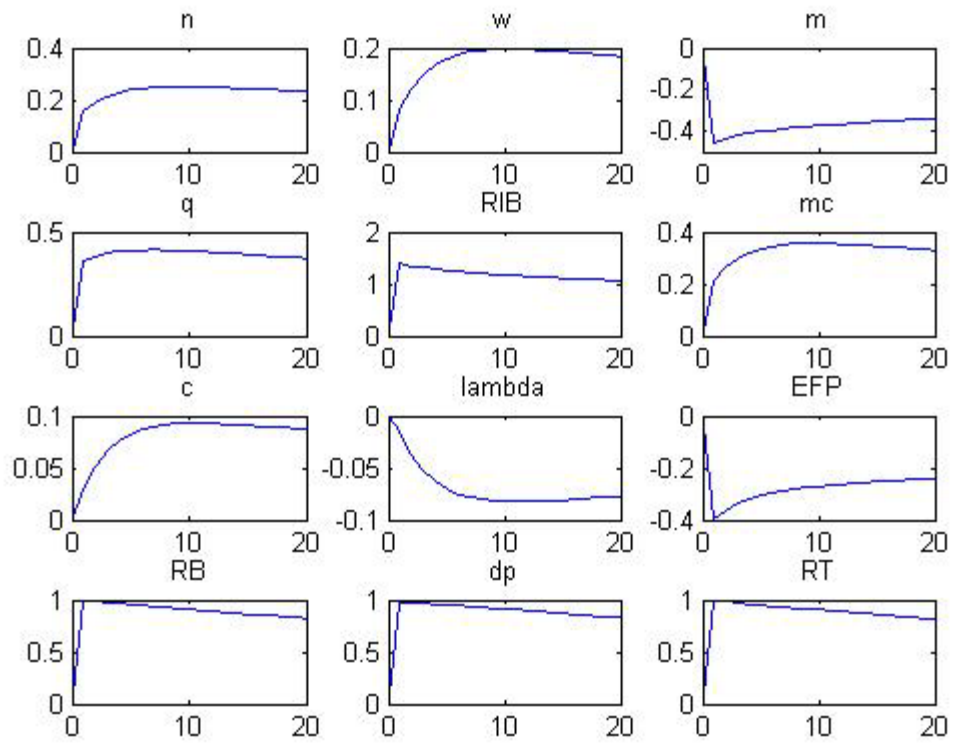
Fig. 2: Responses to unit shock to edh
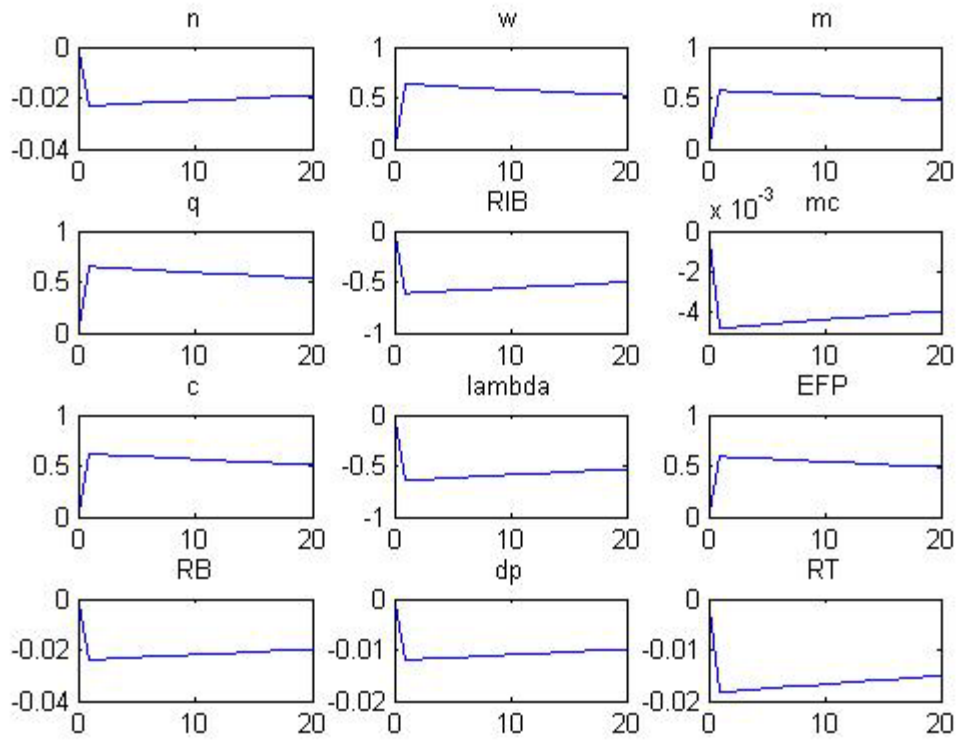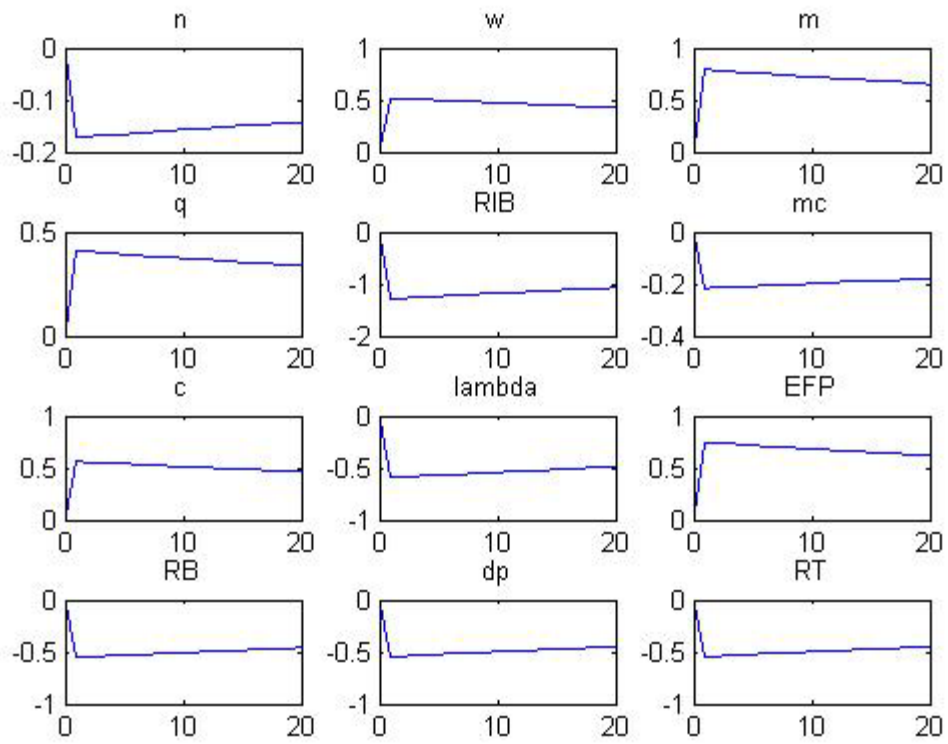

Fig. 3: Responses to unit shock to a1
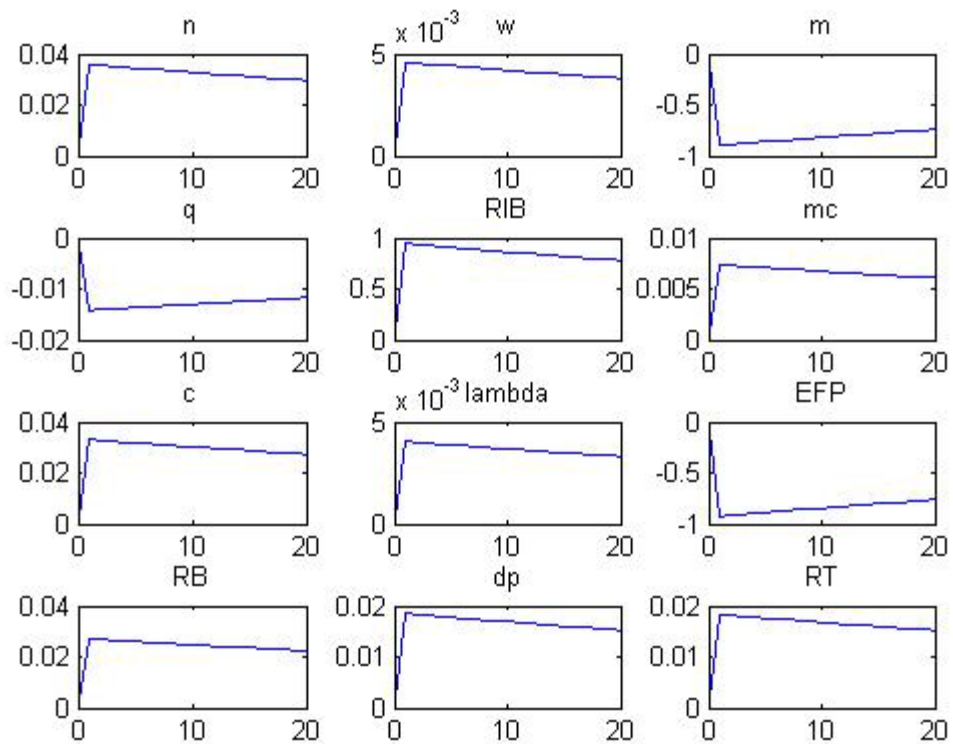
Fig. 4: Responses to unit shock to a1

Fig. 5: Responses to unit shock to a2

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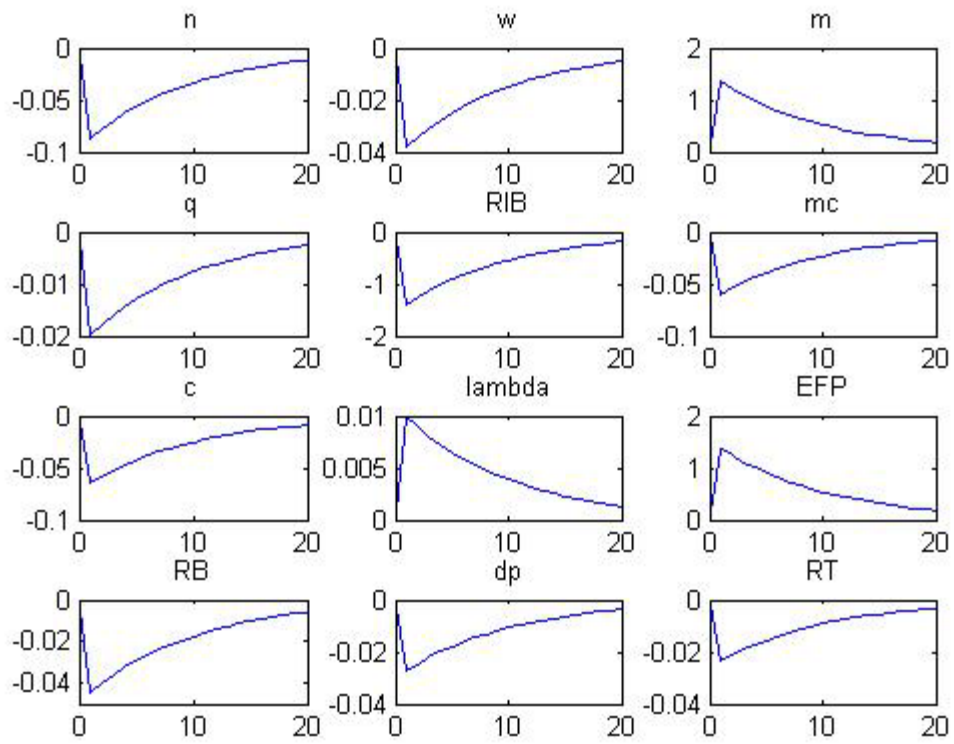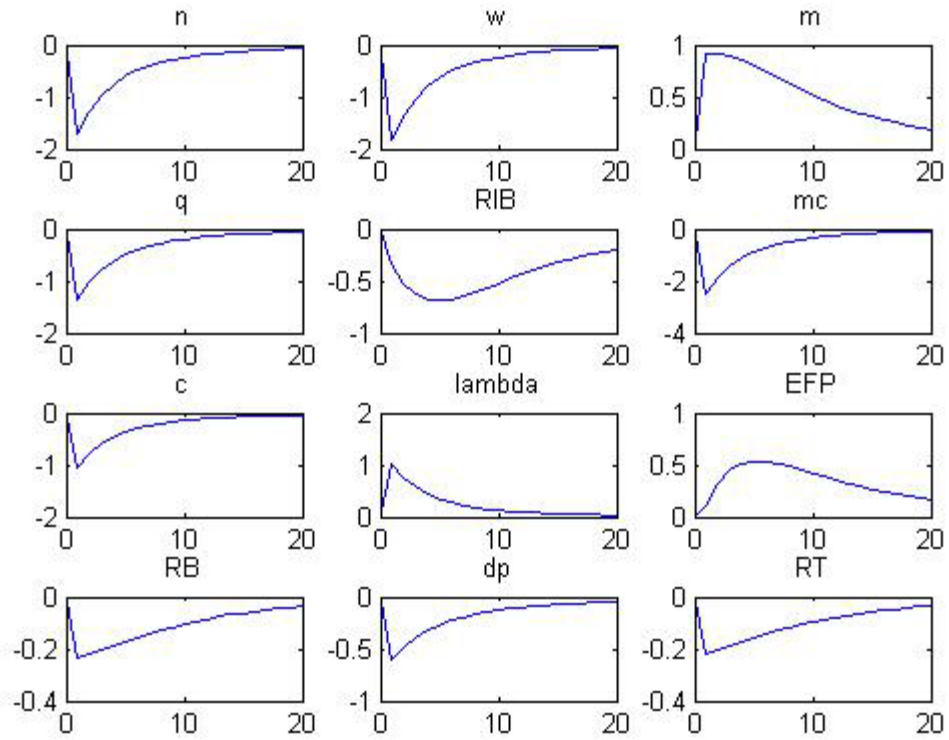
Fig. 6: Responses to unit shock to -a3

Fig. 7: Responses to unit shock to -a3

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