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DOCTORAL DISSERTATION

Banking Stress and Interest Rate Spreads in Macroeconomics

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For the love of my life, Hanieh.

Abstract

The broad objective of this dissertation is to investigate: "how should monetary policy analysis account for shocks to the productivity of banking system and interest rate spreads?" What is meant by monetary policy analysis is the standard modern macroeconomic framework famously called the New Neoclassical Syntheses (NNS) or New Keynesian. By productivity of banking system, it considers banks' economic activities to supply transaction-facilitating deposits that constitute (broad) money in the economy. By interest rate spreads, differences among short-term common-maturity risk-less returns are meant. Specifically, these are spreads between four interest rates: the bank loan rate, the interbank rate, the government bond rate and the deposit rate. The dissertation contributes both theoretically and quantitatively.

The first chapter (co-authored with Marvin Goodfriend) constructs the underlying framework used in other chapters with some variations. Previous research that studies the role of money and banking and interest rate spreads in standard NNS framework (as in the seminal work of Goodfriend and McCallum (2007)) has chiefly focused on the cost of creating deposits via extending loans to private non-bank borrowers that is reflected in the spread between the loan rate and the interbank rate. This chapter complements that research by incorporating banks' behavior to provide payment services to depositors. To this end, it develops a model of interbank market, in which banks can use interbank credit to execute payment orders of depositors. Following previous literature, an interbank loan technology is introduced to overcome the informational asymmetries among banks. Moreover, banks are motivated to hold government debt on their balance sheets to mitigate the cost of monitoring by interbank creditors. This modification enriches prior research to explain spreads between the loan rate, the interbank rate, the government bond rate and the deposit rate in terms of the underlying activities of banks.

The second chapter applies the model to examine banking stress and in particular the three-month EuroDollar–Treasury bill (TED) spread, which is commonly regarded as an indicator of stress in banking. The chapter decomposes variations in the TED spread to factors driven by shocks to banking and collateral. It particularly finds that fluctuation in collateral supply is the dominant driver of the TED spread. Moreover, scarcity of collateral elevates the sensitivity of TED with respect to banking shocks, which could explain the generally smaller spreads in 1990s relative to 1970s. Therefore, distinguishing between the collateral and banking shock effects provides a sharper interpretation of the TED spread as an indicator of banking stress.

The third chapter focuses on monetary policy analysis in the presence of shocks to banking. First, it uses historical observations to quantify and demonstrate the macroeconomic significance of aggregate shocks to productivity of banking under a standard Taylor rule. It then explores the performance of the economy with interest rate policy rule responsive to rate spreads in response to banking stress. The chapter's analysis shows that banking shocks impact the aggregate economy by imposing a tax on aggregate consumption. To best mitigate real effects of banking shocks, monetary policy should react to an interest rate spread that best mimics variations in the banking tax. The chapter finds that the loan-deposit spread is the best candidate among others.

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Chapter 1

Macroeconomics of Banking Services, Collateral and Interest Rate Spreads

with Marvin Goodfriend

The chapter presents a theory of money and banking in an otherwise standard representative agent new synthesis model. Government debt held by households defrays the cost of borrowing from banks to finance deposits; and government debt held by banks facilitates the production of interbank credit in the provision of transactions services on deposits. Therefore, the economy-wide collateral services yield is determined in general equilibrium by integrating the household and bank demand for collateral. The calibrated model is employed to assess the quantitative impact on various interest rate spreads of three policy exercises: an increase in the supply of government debt, an increase in aggregate bank reserves, and an exchange of government debt for bank reserves. The model predicts that a central bank open market purchase of debt for bank reserves creates a net scarcity of collateral, which raises the collateral services yield and elevates other rate spreads.

1.1 Introduction

Banks play a crucial role in a monetary economy; they issue deposits, which facilitate transaction services. However, issuing (creating) and servicing deposits are costly and take up resources. Therefore, economists, central bankers and government authorities have wondered how monetary policy and government debt policy affect costs of banking. The present paper addresses this question in terms of interest rate spreads by building on Goodfriend and McCallum (2007) who develop a new Keynesian model augmented with money and banking.

Goodfriend and McCallum (2007) argue that deposits are created once banks extend illiquid loans to households by employing ex ante monitoring effort to avoid ex post default. Moreover, government debt (and other collateral securities) held by households could defray the cost of monitoring. However, their model (like other models in the literature) abstracts from costly provision of transaction services by banks. Furthermore, they do not allow banks to hold government debt, whereas historical data show banks hold significant amount of government debt on their balance sheet. Finally, their calibration implies the interbank–government bond spread is -125 basis points whereas the spread is consistently observed to be positive with an average of one percentage point from 1971 to 2006 (See Figure 1).

The present research resolves these shortcomings by evaluating the cost of servicing deposits via the opportunity cost of using interbank credit for executing payments. Interbank lenders should be compensated for monitoring the interbank borrower, the cost of which could be defrayed when the interbank borrower holds government debt on its balance sheet[1]. In this way, banks value government debt for their collateral services and in equilibrium, the bond rate falls below the interbank rate[2] by collateral services yield. Finally, the paper shows that a plausible calibration of the model exists that matches average observed interbank–government bond spread.

The present research contributes to the literature both theoretically and quantitatively. Among its theoretical findings, the research finds that government debt held by banks is valued for two reasons. First, it provides collateral services to banks in the interbank market. Second, by virtue of substituting with loans to households on bank asset composition, it saves on the external finance premium costs[3]. The combination of these two components should equal the collateral services yield of government debt to households in equilibrium. Accordingly, the economy-wide collateral services yield is determined by integrating the household and bank demand for collateral equaling total supply of collateral. Moreover, this research illustrates how spreads between various interest rates are associated with valuation of collateral and transaction services.

The quantitative findings of the paper are based on a plausible calibration of model parameters to match average values of observable variables in the U.S. economy over 1971 to 2006 (pre-crisis). Specifically, banking parameters are calibrated by using observed average interest rate spreads and other banking aggregates. The parameter values suggest that interbank loan technology is more monitoring-intensive, while loan to household technology is more collateral-intensive. These findings comply with the

[1]A relevant idea is suggested by Bansal and Coleman (1996) who provide a model in which government debt is used to back checkable deposits. Similarly, Gorton (2010) notes a substantial demand for collateral services from government debt in dealing with counterparty risk in derivatives and settlement systems.

[2]The interbank rate accounts for the opportunity cost of loanable funds to the bank and the total return to any asset held by the bank should be equal to the interbank rate.

[3]The total marginal cost of issuing loans to households accounts for the external finance premium in the model, as in GM.

intuition of the research that interbank loans are used for servicing deposits, whereas loan to households result in creation of deposits.

Using the calibrated model, the present research analyzes the market for collateral services and finds a reasonably stable banking demand for government debt collateral throughout the sample period. The analysis also suggests that variations in the interbank–government bond spread (the TED spread) is decomposed into two components: (i) the secular variation in the TED spread is explained by the secular variation in the supply of government debt relative to GDP (collateral supply effects), and (ii) the remaining component (spikes) in the TED spread is attributed to temporary shocks to banking productivity (collateral demand effects). Spikes in the TED spread purged of collateral supply effects facilitate measuring and ranking underlying banking distress in various banking crises during the sample period.

Finally, the calibrated model is used for evaluating implications for various rate spreads and other variables relevant to money and banking of three policy exercises on balanced growth equilibrium: (1) lower supply of government debt, (2) higher bank reserves and (3) open market purchase of government debt. Using the first exercise, the paper finds empirical support for its calibration by replicating empirical finding by Krishnamurthy and Vissing-Jorgensen (2012). Specifically, a standard deviation decrease in the supply of government debt relative to GDP results in 111 basis-point increase in the CD–T-bill spread[4] according to K-V that matches roughly well with the 164 basis-point increase in the TED spread according to our calibrated model. The second quantitative exercise finds that in equilibrium with higher bank reserves, banks hold more government debt on their balance sheet reducing their loans to households, which in turn leads to smaller external finance premium. However, while marginal cost of interbank loan production decreases, because of additional reserves that pay no interest, the marginal cost of transaction services gets higher. Finally, the calibrated model shows that open market purchase of government debt, i.e. an equilibrium with higher bank reserves and equally lower government debt supply, implies a more expensive banking and widened spreads. This is because there is scarcity of collateral in the new equilibrium, the effect of which is stronger than smaller loan production to households.

The paper is organized as follows. Sections 2 and 3 describe the model and corresponding first order conditions of the representative agent. Based on these conditions, sections 4, 5 and 6 discuss valuation of collateral services and transaction services as well as the link between observable and shadow rates. This facilitates comprehensive connection between various interest rates of the model that is illustrated in section 7. General equilibrium and balanced-growth conditions are presented in sections 8 and 9. Section 10 describes calibration of parameters of the model. Section 11 includes

[4]Historical observations indicate a negligible difference between the TED and CD-T-bill spreads.

analysis and decomposition of the TED spread using the calibrated model. Section 12 presents analysis of three policy exercises under the calibrated model. Finally, section 13 provides concluding remarks and future directions.

1.2 The Model

The model of this paper builds on Goodfriend and McCallum (2007) (GM) who present a new Keynesian model enhanced with costly money and banking. Like GM, the economy is populated with many alike households. Each household owns a bank that operates by competitively issuing loans to other households, which immediately result in creation of deposits. Deposits are demanded to facilitate transactions in a simple cash-in-advance way, which allows us to focus on the analysis of costs of producing and servicing deposits by banks. The point of departure of the model from GM is that to service payment orders of its depositors momentarily, each bank is assumed to borrow credit from a competitive interbank market immediately, which is costly because it involves monitoring the balance sheet health of the bank by the interbank creditor. Therefore, unlike GM, in the money and banking model of the present research, servicing deposits is costly.

To clarify the role of costly issuing and servicing deposits by banks, the section first discusses the money and banking sector and then characterizes the problem of the representative household. The assumption that the representative household is the owner of a bank, then allows us to characterize valuation of demand and supply of monetary services in equilibrium.

1.2.1 Money and Banking

At the beginning of each period, each household realizes its demand for transaction services, for which it holds bank deposits[5] that provide immediately available funds during the period. Like GM, real deposit demand by the household is assumed to follow,

$$\frac{D_t^d}{P_t^A} \geqslant \frac{1}{V} c_t \tag{1.2.1}$$

where D_t^d represents the nominal deposit demand, P_t^A represents aggregate price level and c_t represents consumption at period t. V is a constant expressing the velocity of real deposit circulation.

An individual bank supplies deposit contracts, D_t^s, according to which it is liable to execute payments at a moment's notice from the deposit holder. Deposits are created in either of the following ways: when a household (a) borrows funds, L_t^h, from a bank

[5] Note that by assumption, a household receives banking services from a bank other than it owns.

due at the end of the period, (b) sells government bonds, B^b_{t+1}, to the bank, or (c) deposits reserves, H_t, at a bank. Therefore, the balance sheet equality of a typical bank (in real terms) is given by,

$$\frac{L^h_t}{P^A_t} + \frac{B^b_{t+1}}{P^A_t(1+R^B_t)} + \frac{H_t}{P^A_t} \equiv \frac{D^s_t}{P^A_t} \tag{1.2.2}$$

where R^B_t denotes the government bond rate. The individual bank extends real loans to households, $\frac{L^h_t}{P^A_t}$, by employing workers to monitor the household, m^d_t, the cost of which could be defrayed when the borrower holds collateral securities. Household collateral consists of [6] government debt, B^h_{t+1}, and physical capital K_{t+1} (priced at q_t) at a lesser degree captured by parameter k. As suggested by GM, real loans to households follows the following constraint[7],

$$\frac{L^h_t}{P^A_t} \leqslant F\left(\frac{B^h_{t+1}}{P^A_t(1+R^B_t)} + kq_tK_{t+1}\right)^{\alpha}(A^m_t m^d_t)^{1-\alpha} \tag{1.2.3}$$

where A^m_t represents shock to productivity of monitoring effort.

In order to provide transaction services to deposit contracts, a bank is assumed to have two options. It could either hoard reserves on its balance sheet to execute payment orders, or it could borrow credit from the interbank market as soon as it receives a payment order during the period. Because reserves do not pay any interest, there is a high opportunity cost for a bank to hold reserves on its balance sheet. The bank could however reduce the cost of interbank borrowing by positioning its balance sheet by government debt. In this way, due to high safety of government debt, it could defray the cost of monitoring by interbank creditors and receive a more favorable interbank rate. As a result, the bank will choose to hold minimal reserves and execute transactions via interbank loans. It is assumed an individual bank chooses to hold reserves on its balance sheet proportionate to its supply of deposits,

$$\frac{H_t}{P^A_t} \geqslant rr\frac{D^s_t}{P^A_t} \tag{1.2.4}$$

Note that an individual bank borrows interbank credit, $\frac{L^b_t}{P^A_t}$, to facilitate payments

[6]Note that because deposits are immediately available funds, they do not offer any collateral services to depositors.

[7]The model assumes that ex ante monitoring of borrower who pledges collateral ensures repayment of loans, thereby assuming away default on issued loans. Recovery of a loan is ensured by ex ante evaluation of human capital of the borrower, which implies the cash-flow generation capacity of the borrower's activities using the borrowed funds and backed by the liquidation value of collateral. The banking intermediary in effect creates value by channeling funds to businesses by virtue of such monitoring expertise. As long as the value of a loan is smaller than the sum of tangible collateral and human capital, no default takes place.

during the period, when its inflow of funds and payment orders do not synchronize. Since demand for transaction services is proportionate to real deposit demand, a representative bank's demand for interbank credit is simply assumed to be given by,

$$\frac{L_t^b}{P_t^A} \equiv \ell \frac{D_t^s}{P_t^A} \tag{1.2.5}$$

The paper adopts a similar loan production technology for interbank credit as loans to households relation 2.1.7. The interbank creditor exerts monitoring effort, $\tilde{m}_t$, which could be defrayed when the interbank debtor holds larger government debt[8] on its balance sheet. Therefore, the interbank loan production technology is assumed to follow,

$$\frac{L_t^b}{P_t^A} \leqslant \tilde{F} \left(\frac{B_{t+1}^b}{P_t^A(1+R_t^B)} \right)^{\tilde{\alpha}} \left(A_t^{\tilde{m}} \tilde{m}_t^d \right)^{1-\tilde{\alpha}} \tag{1.2.6}$$

where interbank monitoring is augmented by $A_t^{\tilde{m}}$. Note that in the interbank loan production technology as in the loans to households, monitoring costs are incurred by the creditor yet opportunity cost of holding collateral is born by the borrower. However, as GM argue the assumption of perfect competition allows one to solve the problem and find optimal conditions as if all costs are incurred by one party. This is going to be the approach in characterizing the representative household's problem.

1.2.2 The Representative Household's Problem

All households in the model are identical. The representative household's objective function is,

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

At every period, households may choose to supply labor to production sector, n_t^s, and monitoring effort, m_t^s and $\tilde{m}_t^s$ in the banking sector. The intertemporal resource

[8] Since reserves on the balance sheet are immediately available funds to banks, they do not provide any collateral services to banks in the interbank market.

constraint is given by,

$$\frac{D_t^s}{P_t^A} + \frac{D_{t-1}^d}{P_t^A}(1 + R_{t-1}^D) + q_t(1-\delta)K_t + \frac{B_t^h}{P_t^A} + \frac{B_t^b}{P_t^A} + \frac{H_{t-1}}{P_t^A} + w_t(n_t^s + m_t^s + \tilde{m}_t^s)$$
$$+ c_t^A \left(\frac{P_t}{P_t^A}\right)^{-(\theta-1)} \geqslant \frac{D_t^d}{P_t^A} + \frac{D_{t-1}^s}{P_t^A}(1 + R_{t-1}^D) + q_t K_{t+1} + \frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + \frac{B_{t+1}^b}{P_t^A(1+R_t^B)} + \frac{H_t}{P_t^A}$$
$$+ w_t(n_t^d + m_t^d + e_t^d) + \tau_t + c_t \tag{1.2.7}$$

D_t^s represents the deposits supplied by the household-owned bank, while D_t^d represents the household's demand for deposits from other banks, during period t. Note that deposit market clearance implies net deposits do not take up any resources. R_t^D denotes nominal interest payment on deposits. The household could allocate its government bonds for two uses: (a) collateral against loans from banks, B_t^h, i.e. *household collateral*, and (b) on its bank's balance sheet, B_t^b, i.e. *banking collateral*. Per-period lump-sum government tax is τ_t.

Household-specific production and sales constraint following GM is given by,

$$K_t^\eta \left(A_t^n n_t^d\right)^{1-\eta} - c_t^A \left(\frac{P_t}{P_t^A}\right)^{-\theta} \geqslant 0 \tag{1.2.8}$$

where goods production labor is augmented by A_t^n. Moreover, P_t represents the price set by the household specific production of goods and c_t^A represents total demand for goods.

1.3 First Order Conditions

Optimal conditions for solving the problem of the representative household whose choice also includes banking variables is presented in this section. The representative household's problem is to maximize its expected lifetime utility function subject to the five constraints including money demand constraint, (3.2.2), balance sheet constraint, (2.1.6) and interbank credit constraint to provide transaction services, (2.1.8), intertemporal resource constraint, (3.2.3), and production and sales constraint, (3.2.4). The corresponding Lagrange multipliers for each of these constraints are denoted by ν_t, Ψ_t, ψ_t, λ_t and ξ_t respectively. These multipliers are shown in the following three sections to represent valuation of collateral, banking and transaction services and are interpreted in terms of interest rate spreads.

Accordingly, the representative household chooses 16 variables including eleven endogenous variables, c_t, $\frac{D_t^d}{P_t^A}$, $\frac{D_t^s}{P_t^A}$, n_t^s (or m_t^s or $\tilde{m}_t^s$), n_t^d, P_t, K_{t+1}, b_{t+1}^h, b_{t+1}^b, m_t^d and $\tilde{m}_t^d$ along with five Lagrange multipliers λ_t, ξ_t, ν_t, Ψ_t and ψ_t. Equations (3.3.1) to (2.1.13) along with the five constraints provide conditions for optimal choice of variables by the representative household given aggregate price variables P_t^A, w_t, R_t^B, R_t^D and q_t, aggregate demand c_t^A, and government policy variables τ_t, H_t and shock processes A_t^n, A_t^m and $A_t^{\tilde{m}}$. The set of first order conditions of the household is,

$$\frac{\phi}{c_t} - \lambda_t - \frac{1}{V}\nu_t = 0 \tag{1.3.1}$$

$$-\lambda_t + \nu_t + \beta E_t \left[\lambda_{t+1}\frac{1+R_t^D}{1+\pi_{t+1}}\right] = 0 \tag{1.3.2}$$

$$\lambda_t - rr\,\lambda_t - (1-rr)\Psi_t - \ell\psi_t + rr\,\beta E_t\left(\lambda_{t+1}\frac{1}{1+\pi_{t+1}}\right) - \beta E_t\left[\lambda_{t+1}\frac{1+R_t^D}{1+\pi_{t+1}}\right] = 0 \tag{1.3.3}$$

$$-\frac{1-\phi}{1-n_t^s-m_t^s-\tilde{m}_t^s} + w_t\lambda_t = 0 \tag{1.3.4}$$

$$-w_t\lambda_t + \xi_t(1-\eta)A_t^n\left(\frac{K_t}{A_t^n n_t}\right)^{\eta} = 0 \tag{1.3.5}$$

$$-\lambda_t\left(\frac{c_t^A}{P_t^A}\right)(\theta-1)\left(\frac{P_t}{P_t^A}\right)^{-\theta} + \xi_t\left(\frac{c_t^A}{P_t^A}\right)\theta\left(\frac{P_t}{P_t^A}\right)^{-\theta-1} = 0 \tag{1.3.6}$$

$$-\lambda_t q_t + \Psi_t k q_t F\alpha\left(\frac{A_t^m m_t}{b_{t+1}^h + kq_tK_{t+1}}\right)^{1-\alpha} + \beta E_t\left[\lambda_{t+1}q_{t+1}(1-\delta) + \eta\,\xi_{t+1}\left(\frac{A_{t+1}^n n_{t+1}}{K_{t+1}}\right)^{1-\eta}\right] = 0 \tag{1.3.7}$$

$$-\lambda_t + \Psi_t F\alpha\left(\frac{A_t^m m_t}{b_{t+1}^h + kq_tK_{t+1}}\right)^{1-\alpha} + E_t\left[\frac{\beta\lambda_{t+1}}{1+\pi_{t+1}}\right]\left(1+R_t^B\right) = 0 \tag{1.3.8}$$

$$-\lambda_t + \Psi_t + \psi_t\tilde{F}\tilde{\alpha}\left(\frac{A_t^{\tilde{m}}\tilde{m}_t}{b_{t+1}^b}\right)^{1-\tilde{\alpha}} + E_t\left[\frac{\beta\lambda_{t+1}}{1+\pi_{t+1}}\right]\left(1+R_t^B\right) = 0 \tag{1.3.9}$$

$$-w_t\lambda_t + \Psi_t F(1-\alpha)A_t^m\left(\frac{b_{t+1}^h + kq_tK_{t+1}}{A_t^m m_t}\right)^{\alpha} = 0 \tag{1.3.10}$$

$$-w_t\lambda_t + \psi_t\tilde{F}(1-\tilde{\alpha})A_t^{\tilde{m}}\left(\frac{b_{t+1}^b}{A_t^{\tilde{m}}\tilde{m}_t}\right)^{\tilde{\alpha}} = 0 \tag{1.3.11}$$

1.4 Collateral Services Pricing

Using the conditions for optimal choice of endogenous variables presented in the previous section, this section displays valuation of collateral services by the representative agent. Remember that government debt could be held by a household serving as collateral against its loans from banks or held on the balance sheet of household-owned bank. In the latter case, government debt provides collateral services to household-owned bank. No-arbitrage conditions derived from optimal allocation of government debt is thus demonstrated in this section.

1.4.1 Shadow Total Yield

As a primary step to understand collateral services valuation in the model, the paper introduces a benchmark total risk-adjusted yield that equals the risk-adjusted total return of any asset held by the household. The shadow total return denoted by R_t^T is determined according to the famous Euler equation (1.3.8) by defining a fictitious one-period default-free security that provides no collateral services to its holder and it satisfies,

$$\frac{1}{1+R_t^T} = E_t\left[\frac{\beta\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\right] \tag{1.4.1}$$

The total opportunity cost of any asset held by the household equals shadow total return, which is accordingly used to discount any future monetary return. Equation (3.2.13) essentially displays the present value of a nominal dollar at the next period.

It is important to note that the total yield is determined based on macroeconomic equilibrium. Other interest rates of the model are different from the total yield because of the costly creation and provision of banking services.

1.4.2 Household Collateral Services Yield

Using the definition of total yield (3.2.13) in optimal condition for household collateral demand (1.3.8),

$$\frac{1+R_t^B}{1+R_t^T} + \underbrace{\frac{\Psi_t}{\lambda_t}F\alpha\left(\frac{A_t^m m_t}{b_{t+1}^h + kq_tK_{t+1}}\right)^{1-\alpha}}_{\text{Household Collateral Services Yield}} = 1 \tag{1.4.2}$$

Equation (1.4.2) reveals that a dollar present value of holding government bonds by the households equals present value of nominal return on government bonds (the first term on the left) and a non-pecuniary return components that accounts for collateral services to households from holding government bonds, thereby values household collateral services.

In other words, optimal choice of household collateral requires the foregone pecuniary return due to holding government bonds (the spread between R^T and R^B) equal collateral services valuation of government bonds by households in acquiring loans from banks (household collateral services yield).

1.4.3 External Finance Premium

The implications of the theory of factor pricing is central to the analysis of production of banking services in the model. Remember the optimal choice of factors requires the opportunity cost of employing a primary factor equal the value of marginal product of that factor. In a perfectly competitive market, $p^y = MC$. Optimal choice of factor x_i is achieved when,

$$p^{x_i} = MC \times MP_i \tag{*}$$

Applying the optimal factor pricing condition to household collateral services yield expression in equation (1.4.2),

$$\underbrace{1 - \frac{1+R_t^B}{1+R_t^T}}_{\text{Opp Cost of Holding Gov Bonds}} = \underbrace{\frac{\Psi_t}{\lambda_t}}_{\text{MC of Loan Prod}} \underbrace{\times F\alpha \left(\frac{A_t^m m_t}{b_{t+1}^h + kq_t K_{t+1}} \right)^{1-\alpha}}_{\text{MP of hh Collateral}} \tag{1.4.3}$$

This interpretation is also seen using the optimal monitoring effort demand condition given by (2.1.12) written in the format of (*),

$$\underbrace{w_t}_{\text{Monitoring Factor price}} = \underbrace{\frac{\Psi_t}{\lambda_t}}_{\text{MC of Loan Prod}} \underbrace{\times F(1-\alpha) A_t^m \left(\frac{b_{t+1}^h + kq_t K_{t+1}}{A_t^m m_t} \right)^{\alpha}}_{\text{MP of Monitoring}} \tag{1.4.4}$$

Marginal cost of loan production makes up the *external finance premium* with perfect competition in the loan market of the model. Note that the expression for the external finance premium, Ψ/λ, accounts for valuation of balance sheet capacity to create deposits in terms of a unit of consumption.

1.4.4 Shadow Interbank Rate

Analogous to total shadow return, introduce a benchmark total risk-adjusted return for any asset on the balance sheet of a bank. The shadow total risk-adjusted return denoted by $R_t^{IB,T}$ is determined by (2.1.11) by defining a fictitious one-period asset on the balance sheet of the bank that accounts for a dollar of loanable funds, which does not provide any collateral services for interbank borrowing. Applying the definition of total yield (3.2.13) in optimal condition for banking collateral demand (2.1.11) satisfies,

$$\frac{1+R_t^{IB,T}}{1+R_t^T} + \underbrace{\frac{\Psi_t}{\lambda_t}}_{\text{EFP}} = 1 \tag{1.4.5}$$

Equation (2.1.23) displays the present value of a dollar of loans to household in terms of its costs, which is split into the present value of the total opportunity cost of loanable funds to a bank, e.g. one-period interbank credit, and the total marginal cost of loan production, i.e. the external finance premium. External finance premium cost equals the gap between the total yield and the opportunity cost of loanable funds to a bank.

1.4.5 Banking Collateral Services Yield

Using (2.1.23) and (3.2.13) in (2.1.11),

$$\frac{1+R_t^B}{1+R_t^T} + \underbrace{\frac{\psi_t}{\lambda_t}\tilde{F}\tilde{\alpha}\left(\frac{A_t^{\tilde{m}}\tilde{m}_t}{b_{t+1}^b}\right)^{1-\tilde{\alpha}}}_{\text{Banking Collateral Service Yield}} = \frac{1+R_t^{IB,T}}{1+R_t^T} \tag{1.4.6}$$

According to (1.4.6), the present value of the total return on government bonds to a bank is split between the present value of nominal return on government bonds and a non-pecuniary return component that reflects collateral services to the bank from holding government bonds on its balance sheet, thereby valuing banking collateral services.

In other words, optimal choice of banking collateral requires the opportunity cost of holding a dollar of government bonds on the balance sheet equal internal valuation of collateral services of government bonds from a bank's perspective.

Applying the optimal factor pricing condition (*) to banking collateral services yield expression in (1.4.6),

$$\underbrace{\frac{1+R_t^{IB,T}}{1+R_t^T} - \frac{1+R_t^B}{1+R_t^T}}_{\text{Opp Cost of holding gov bonds to a bank}} = \underbrace{\frac{\psi_t}{\lambda_t}}_{\text{MC of Interbank Credit}} \times \underbrace{\tilde{F}\tilde{\alpha}\left(\frac{A_t^{\tilde{m}}\tilde{m}_t}{b_{t+1}^b}\right)^{1-\tilde{\alpha}}}_{\text{MP of banking Coll}} \tag{1.4.7}$$

This interpretation is also seen using the optimal interbank monitoring effort demand condition given by (2.1.13) written in the format of (*),

$$\underbrace{w_t}_{\text{Interbank Monitoring Factor price}} = \underbrace{\frac{\psi_t}{\lambda_t}}_{\text{MC of Interbank Credit Prod}} \times \underbrace{\tilde{F}(1-\tilde{\alpha})A_t^{\tilde{m}}\left(\frac{b_{t+1}^b}{A_t^{\tilde{m}}\tilde{m}_t}\right)^{\tilde{\alpha}}}_{\text{MP of Monitoring}} \tag{1.4.8}$$

Note that the marginal cost of interbank credit production, ψ/λ, evaluates the capacity of transaction services provision via interbank credit (2.1.8) and (2.1.9).

Using (3.2.13), the optimal condition for holding government bonds on the balance sheet of the household-owned bank, (2.1.11) can be rewritten as,

$$\frac{1+R_t^B}{1+R_t^T} + \underbrace{\frac{\Psi_t}{\lambda_t}}_{\text{EFP}} + \underbrace{\frac{\psi_t}{\lambda_t}\tilde{F}\tilde{\alpha}\left(\frac{A_t^{\tilde{m}}\tilde{m}_t}{b_{t+1}^b}\right)^{1-\tilde{\alpha}}}_{\text{VMP of Gov Bonds in IB loans}} = 1 \tag{1.4.9}$$

According to (1.4.9), the present value of a dollar of government bond holding on the balance sheet of its bank is valuable to the household, because in addition to providing pecuniary return, as an item on the asset side of the balance sheet it supports a dollar of deposit creation without incurring the external finance premium costs, and in addition, it is productive in economizing on the costs of obtaining interbank loans.

Note that the no arbitrage condition for uses of government bonds by the household is satisfied by consistently pricing government bonds via (1.4.2) and (1.4.9) (counterparts for (1.3.8) and (2.1.11) respectively).

1.5 Transaction Services Pricing

Similar to the previous section, using optimal conditions of the representative household, this section demonstrates how transaction services are priced in the model. The household values transaction services from two perspectives: (a) demand for transaction services to execute payments during the period, and (b) provision of transaction services by the household-owned bank.

1.5.1 Transaction Services Yield

Using optimal condition for deposit demand (2.1.3) and the definition of total yield (3.2.13),

$$\frac{1+R_t^D}{1+R_t^T} + \underbrace{\frac{\nu_t}{\lambda_t}}_{\text{Transaction Services Yield}} = 1 \tag{1.5.1}$$

According to (1.5.1), the household values the present value of a dollar of its deposits by the combination of the present value of nominal returns paid on the deposits and the transaction services facilitated via the deposits. The relation shows that the foregone pecuniary interest due to holding deposits equals the transaction services yield of deposits. Note that the expression for transaction services yield of deposits, ν/λ, reflects the valuation of the transaction demand (3.2.2) by the representative household.

1.5.2 Total Marginal Cost of Issuing and Servicing Deposits

Using optimal condition for deposit supply by the household-owned bank (2.1.10) and the definition of total yield (3.2.13),

$$\frac{1+R_t^D}{1+R_t^T}+rr\left(1-\frac{1}{1+R_t^T}\right)+(1-rr)\frac{\Psi_t}{\lambda_t}+\ell\frac{\psi_t}{\lambda_t}=1 \tag{1.5.2}$$

According to (1.5.2), the total cost of the present value of a dollar value of issuing deposits by the household-owned bank can be decomposed into the following components: present value of nominal interest payments, the opportunity cost of minimum reserve ratio holding (reserve tax), marginal cost of loan production and the marginal cost of providing transaction services for the deposits via interbank loans.

Noting that the external finance premium accounts for the total marginal cost of creation of deposits allows for backing out marginal cost of transaction services provision for deposits. Using (2.1.23) in (1.5.2),

$$1-\frac{1+R_t^D}{1+R_t^T}=\underbrace{\frac{\Psi_t}{\lambda_t}}_{\text{EFP}}+\underbrace{rr\left(\frac{R_t^{IB,T}}{1+R_t^T}\right)+\ell\frac{\psi_t}{\lambda_t}}_{\text{MC of transaction services provision}} \tag{1.5.3}$$

According to (1.5.3), marginal cost of transaction provision for issuing a real dollar of deposits can be attributed to reserve tax arising due to non-interest bearing minimum reserve holding and the marginal cost of interbank credit to allow a bank to execute transaction orders of its depositors. The multiplier ℓ transforms marginal cost of a dollar of interbank loans in terms of a dollar of deposits (look at (2.1.8)).

Substituting out for EFP and rewriting (1.5.3)

$$\frac{1+R_t^D}{1+R_t^T}+\ell\frac{\psi_t}{\lambda_t}=\frac{1+(1-rr)R_t^{IB,T}}{1+R_t^T} \tag{1.5.4}$$

Equation (1.5.4) displays funding interbank loans via collecting a real dollar of deposits to a bank. A real dollar of deposits is costly for a bank due to nominal interest payments and cost of providing transaction services. The bank can however, earn interbank interest on $1-rr$ fraction of the deposit funds due to minimum reserve ratio constraint. Because reserves do not pay interest, the foregone interest due to holding them on the balance sheet is equal to the shadow interbank rate.

In the special case of zero marginal cost of interbank credit, (1.5.4) is simplified to,

$$R_t^D=(1-rr)R_t^{IB} \tag{1.5.5}$$

Relation (1.5.5) replicates equation (24) in GM in which the provision of transaction services and hence interbank credit is assumed to be done costlessly.

1.6 Market versus Shadow Interest Rates

The previous two sections displayed how collateral and banking services are valued by appropriately defining shadow returns i.e. the shadow total yield, R_t^T and the shadow interbank rate, $R_t^{IB,T}$. This section shows how observable rates i.e. the market loan rate, R_t^L, and the market interbank rate, R_t^{IB} are determined.

Because the loan markets are perfectly competitive, the total marginal cost of loan production could be decomposed into a component attributed to monitoring effort (incurred by the lender) and another component attributed to collateral (where the foregone pecuniary interest is incurred by the borrower).

Rewriting optimal condition for monitoring effort (2.1.12) and using (2.1.7),

$$\frac{w_t m_t}{\frac{L_t^h}{P_t^A}} = (1-\alpha)\frac{\Psi_t}{\lambda_t} \tag{1.6.1}$$

Equation (1.6.1) shows that average cost of monitoring effort accounts for $(1-\alpha)$ fraction of total marginal cost of loan production. This fraction of external finance premium is accrued to the lenders to compensate for monitoring effort.

Rewriting optimal condition for government bond holding as collateral in household loans (1.4.2) and using (2.1.7),

$$\frac{\left(1-\frac{1+R_t^B}{1+R_t^T}\right)\left(b_{t+1}^h + kq_t K_{t+1}\right)}{\frac{L_t^h}{P_t^A}} = \alpha\frac{\Psi_t}{\lambda_t} \tag{1.6.2}$$

Equation (1.6.2) exhibits the famous property of Cobb-Douglas production that average cost of holding government bonds accounts for α fraction of total marginal cost of loan production, consistent with (1.6.1). This fraction of external finance premium is rebated to the borrower to compensate for defraying monitoring effort by collateral. Hence, the market loan rate denoted by R_t^L satisfies the equilibrium condition,

$$\frac{1+R_t^L}{1+R_t^T} + \underbrace{\alpha\frac{\Psi_t}{\lambda_t}}_{\text{Return to hh Collateral}} = 1 \tag{1.6.3}$$

where

$$\frac{1+R_t^{IB,T}}{1+R_t^T} + \underbrace{(1-\alpha)\frac{\Psi_t}{\lambda_t}}_{\text{MC of monitoring hh's}} = \frac{1+R_t^L}{1+R_t^T} \tag{1.6.4}$$

Equation (1.6.3) shows that taken a real dollar of loans is costly for the borrower because of nominal loan rate payments and the marginal cost of collateral holding.

According to relation (1.6.4), the present value of market loan rate that is charged from the borrower at the end of the period should equal the present value of total cost of obtaining loanable funds to a bank in addition to marginal cost of employing monitoring effort.

Similarly, the total marginal cost of interbank credit can be decomposed with respect to primary factors of interbank credit extension.

Rewriting optimal condition for interbank monitoring (2.1.13) and using 2.1.9,

$$\frac{w_t \tilde{m}_t}{\frac{L_t^b}{P_t^A}} = (1 - \tilde{\alpha}) \frac{\psi_t}{\lambda_t} \tag{1.6.5}$$

According to (1.6.5), the interbank creditor incurs $(1 - \tilde{\alpha})$ fraction of the total marginal cost of interbank credit and is accordingly compensated. Rewriting optimal condition for government bond holding on the balance sheet of a bank (1.4.6)

$$\frac{\left(\frac{1+R_t^{IB,T}}{1+R_t^T} - \frac{1+R_t^B}{1+R_t^T}\right) b_{t+1}^b}{\frac{L_t^b}{P_t^A}} = \tilde{\alpha} \frac{\psi_t}{\lambda_t} \tag{1.6.6}$$

Hence, the market interbank loan rate denoted by R_t^{IB} satisfies the equilibrium condition,

$$\frac{1 + R_t^{IB}}{1 + R_t^T} + \tilde{\alpha} \frac{\psi_t}{\lambda_t} = \frac{1 + R_t^{IB,T}}{1 + R_t^T} \tag{1.6.7}$$

The relation between the market interbank rate and deposit rate is accordingly,

$$\frac{1 + R_t^D}{1 + R_t^T} + (\ell - (1 - rr)\tilde{\alpha}) \frac{\psi_t}{\lambda_t} = \frac{1 + (1 - rr) R_t^{IB}}{1 + R_t^T} \tag{1.6.8}$$

Equation (1.6.7) shows the decomposition of the total cost of a real dollar of interbank loan production. An interbank borrower incurs the nominal interbank rate payments as well as the marginal cost of holding bonds on its balance sheet. The total cost equals the opportunity cost of a dollar of loanable funds.

The relation between the market interbank rate and government bond rate can be established by the no-arbitrage condition for acquiring a real dollar of government bonds by a bank financed by a real dollar of interbank credit. Using (1.4.6) and (1.6.7),

$$\frac{1 + R_t^B}{1 + R_t^T} + \frac{\psi_t}{\lambda_t} \tilde{F} \tilde{\alpha} \left(\frac{A_t^{\tilde{m}} \tilde{m}_t}{b_{t+1}^b} \right)^{1 - \tilde{\alpha}} = \frac{1 + R_t^{IB}}{1 + R_t^T} + \tilde{\alpha} \frac{\psi_t}{\lambda_t} \tag{1.6.9}$$

Rearranging terms and using (2.1.9), (1.6.9) can be rewritten as,

$$\frac{1+R_t^B}{1+R_t^T}+\frac{\psi_t}{\lambda_t}\tilde{\alpha}\left(\frac{\frac{L_t^b}{P_t^A}}{b_{t+1}^b}-1\right)=\frac{1+R_t^{IB}}{1+R_t^T} \tag{1.6.10}$$

The term in the parenthesis on the left side is positive because in equilibrium the value of interbank loan is larger than the corresponding banking collateral.

1.7 Connection between Interest Rates

The previous three sections showed the interpretation for interest rate spreads in the context of money and banking. To facilitate easy reference and a comprehensive view, this section illustrates a conceptual link between various rates in the model. Moreover, it argues that a positive TED spread essentially implies a loan-to-collateral value that is larger than unity in the model.

1.7.1 Rate Spreads in the Model

Figure 1.2 illustrates how various shadow and market interest rates of the model are decomposed and connected to each other according to pricing equations presented in sections 4, 5 and 6.

In the money and banking approach, the shadow total risk-adjusted return (accounting for both pecuniary and non-pecuniary return components) of any asset held by households equals the total yield, R^T, determined by the Euler equation (3.2.13), which satisfies equilibrium in the real sector. Households demand bank deposits (broad money) to receive transaction services, therefore the deposit rate, R^D, falls below the total yield by the transaction services yield as shown by (1.5.1). In equilibrium, the transaction services yield equals the total marginal cost of issuing loans to households (creation of deposits) as well as the total marginal cost of accessing interbank credit (provision of transaction services to depositors) by banks. The total yield-deposit rate spread is thus decomposed into these two components as shown by (1.5.3). Accordingly, the opportunity cost of loanable funds to a bank namely the shadow interbank rate, $R^{IB,T}$, is lower than the total yield by the total marginal cost of issuing loans to households, i.e. the external finance premium, shown by (2.1.23). Moreover, the shadow interbank rate is higher than the deposit rate by the marginal cost of transaction services provision implied by (1.5.4).

Households could economize on borrowing costs by holding government bonds, which defrays the cost of monitoring by banks resulting in a market loan rate, R^L, lower than the total yield by the return to household collateral as shown by (1.6.3), and higher than the shadow interbank rate by the marginal cost of monitoring as in (1.6.4). As a result, the government bond rate, R^B, falls below the total yield by the household collateral services yield as in (1.4.2).

Similarly, banks economize on interbank borrowing costs by holding government debt to defray the cost of monitoring by interbank creditors, which results in a market interbank rate, R^{IB}, lower than the shadow interbank rate by the return to banking collateral as shown by (1.6.7), and higher than the deposit rate by the marginal cost of interbank monitoring as shown by (1.6.8). Because the opportunity cost of loanable funds to a bank is represented by the shadow interbank rate, the spread between the shadow interbank rate and the government bond rate accounts for the banking collateral services yield in equilibrium as shown by (1.4.6).

1.7.2 The Positive TED Spread and Loan-to-Value Ratio

Following the observation that banks hold significant amount of government debt, the money and banking theory presented in the paper assumes that banks receive collateral services for interbank credit from holding government bonds on their balance sheet. In the setup of the model, a negative TED spread in equilibrium is ruled out, because as soon as the government bond rate rises above the interbank rate, no bank would be motivated to lend interbank credit, while demand for interbank credit would persist as the least expensive option to provide transaction services. Accordingly, the interbank rate would rise until interbank credit market clears at a positive TED spread.

The positive TED spread implies a lower bound in excess of unity for loan to weighted value of collateral (loan-to-value) ratio in the money and banking approach that is crucial in the policy analysis. This is described in several steps.

1. The TED spread is by definition the difference between household collateral services yield, denoted by LSY^{HColl}, and the external finance premium. To see this, rewrite positive TED inequality as

$$\underbrace{R^{IB,T} - R^B}_{\text{TED}} = \underbrace{\left(R^T - R^B\right)}_{LSY^{HColl}} - \underbrace{\left(R^T - R^{IB,T}\right)}_{\text{EFP}} > 0 \Rightarrow LSY^{HColl} > \text{EFP} \tag{1.7.1}$$

2. Optimal factor utilization condition in the household loan market implies,

$$MP^{HColl} \times \text{EFP} = LSY^{HColl} \tag{1.7.2}$$

3. (1.7.1) and (1.7.2) imply marginal product of household collateral is larger than 1, i.e. $MP^{HColl} > 1$.

4. The Cobb-Douglas loan production technology implies,

$$MP^{HColl} = \frac{\alpha\, L^h}{HColl} \Rightarrow MP^{HColl} = \alpha \times LTV \tag{1.7.3}$$

where weighted household collateral is defined as $HColl = B^h + kK$.

5. The result of step 4 and (1.7.3) together impose a lower bound on loan-to-value ratio,

$$LTV > \frac{1}{\alpha} > 1 \tag{1.7.4}$$

The last inequality follows because by structure $\alpha < 1$.

To put the result into perspective, note that to issue a loan, the lender monitors the borrower in addition to the collateral posted by the borrower. Monitoring is interpreted as evaluating the human capital collateral of the borrower, which ensures sufficient cash generating ability of the borrower's activities until maturity of the loan and hence repayment of the loan. As a result, a loan-to-value ratio of e.g. 2.5 implies that the evaluated value of human capital collateral is 1.5 times the physical weighted collateral posted by the borrower. In other words, on average a borrower with high ability to generate cash flows holds collateral against 40% of the funds he borrows from a bank. This approach offers a new explanation for the motivation of a borrower to hold low-yielding collateral assets such as government bonds.

1.8 General Equilibrium

In order to evaluate quantitative implications of the model, the first step is to characterize general equilibrium. General equilibrium conditions of the model include first order conditions of the representative household as well as market clearance conditions and policy rules[9]. Accordingly, the following conditions hold: symmetric pricing among households $P_t = P_t^A$, labor markets clearance $n_t^s = n_t^d$, $m_t^s = m_t^d$ and $e_t^s = e_t^d$. In addition, $q_t = 1$. Fiscal authority is assumed to issue (real present value of) government debt as a fixed fraction of real output at each period, i.e. $b_{t+1} = \bar{b}\, c_t$. The monetary authority determines high-powered money such as to control inflation at a constant rate. The government budget constrain follows,

$$g_t - \tau_t = \frac{H_t}{P_t^A} - \frac{H_{t-1}}{P_t^A} + \frac{B_{t+1}}{P_t^A(1+R_t^B)} - \frac{B_t}{P_t^A}$$

The government expenditure, g_t, is normalized to zero.

[9]There are also transversality conditions as side conditions.

General equilibrium conditions can be written in terms of interest rates, which solve for equilibrium paths of 15 variables c_t, D_t/P_t, R_t^B, n_t, w_t, K_{t+1}, b_{t+1}^h, b_{t+1}^b, m_t, $\tilde{m}_t$, λ_t, ξ_t, R_t^T, $R_t^{IB,T}$ and R_t^D given exogenous shock processes A_t^n, A_t^m and $A_t^{\tilde{m}}$.

$$V\left(\frac{\phi}{c_t\lambda_t}-1\right)=\frac{R_t^T-R_t^D}{1+R_t^T} \tag{1.8.1}$$

$$\frac{1}{1+R_t^T}=E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\right] \tag{1.8.2}$$

$$\frac{1-\phi}{1-n_t-m_t-\tilde{m}_t}=w_t\lambda_t \tag{1.8.3}$$

$$w_t\lambda_t=\xi_t(1-\eta)A_t^n\left(\frac{K_t}{A_t^n n_t}\right)^\eta \tag{1.8.4}$$

$$(\theta-1)\lambda_t=\theta\xi_t \tag{1.8.5}$$

$$q_t=kq_t\left(R_t^T-R_t^{IB,T}\right)F\alpha\left(\frac{A_t^m m_t}{b_{t+1}^h+kq_tK_{t+1}}\right)^{1-\alpha}+E_t\left(\frac{\beta\lambda_{t+1}}{\lambda_t}(1-\delta)q_{t+1}\right)$$
$$+E_t\left(\frac{\beta\lambda_{t+1}}{\lambda_t}\eta\frac{\xi_{t+1}}{\lambda_{t+1}}\left(\frac{A1_{t+1}n_{t+1}}{K}\right)^{1-\eta}\right) \tag{1.8.6}$$

$$R_t^T-R_t^B=\left(R_t^T-R_t^{IB,T}\right)F\alpha\left(\frac{A_t^m m_t}{b_{t+1}^h+kq_tK_{t+1}}\right)^{1-\alpha} \tag{1.8.7}$$

$$R_t^{IB,T}-R_t^B=\frac{1}{\ell}\left((1-rr)R_t^{IB,T}-R_t^D\right)\tilde{F}\tilde{\alpha}\left(\frac{A_t^{\tilde{m}}\tilde{m}_t}{b_{t+1}^b}\right)^{1-\tilde{\alpha}} \tag{1.8.8}$$

$$w_t=\left(\frac{R_t^T-R_t^{IB,T}}{1+R_t^T}\right)F(1-\alpha)A_t^m\left(\frac{b_{t+1}^h+kq_tK_{t+1}}{A_t^m m_t}\right)^\alpha \tag{1.8.9}$$

$$w_t=\frac{1}{\ell}\left(\frac{(1-rr)R_t^{IB,T}-R_t^D}{1+R_t^T}\right)\tilde{F}(1-\tilde{\alpha})A_t^{\tilde{m}}\left(\frac{b_{t+1}^b}{A_t^{\tilde{m}}\tilde{m}_t}\right)^{\tilde{\alpha}} \tag{1.8.10}$$

$$K_t^\eta(A_t^n n_t)^{1-\eta}=c_t+q_t(K_{t+1}-(1-\delta)K_t) \tag{1.8.11}$$

$$b_{t+1}^h+b_{t+1}^b=\bar{b}\ c_t \tag{1.8.12}$$

$$V\frac{D_t}{P_t}=c_t \tag{1.8.13}$$

$$F\left(b_{t+1}^h+kq_tK_{t+1}\right)^\alpha(A_t^m m_t)^{1-\alpha}+b_{t+1}^b=(1-rr)\frac{D_t}{P_t} \tag{1.8.14}$$

$$\tilde{F}\left(b_{t+1}^b\right)^{\tilde{\alpha}}(A_t^{\tilde{m}}\tilde{m}_t)^{1-\tilde{\alpha}}=\ell\frac{D_t}{P_t} \tag{1.8.15}$$

Once the model is solved, the market loan rate and the interbank rate are determined according to,

$$R_t^L = (1-\alpha)\, R_t^T + \alpha\, R_t^{IB,T} \tag{1.8.16}$$

$$R_t^{IB} = \left(1 - \frac{\tilde{\alpha}}{\ell}(1-rr)\right) R_t^{IB,T} + \frac{\tilde{\alpha}}{\ell}\, R_t^D \tag{1.8.17}$$

1.9 Balanced Growth

The next step in exploring the quantitative implications of the model is to show the balanced growth equilibrium of the model.

The balanced growth equilibrium follows the labor augmenting production function, $A_t^n = A_0^n(1+\gamma)^t$. The labor-augmenting shocks to monitoring effort in loan productions grow at the same rate, i.e. $A_t^m = A_0^m(1+\gamma)^t$ and $A_t^{\tilde{m}} = A^{\tilde{m}}(1+\gamma)^t$ to satisfy the balanced growth in the money and banking sector. Normalize $A^n = A^m = A^{\tilde{m}} = 1$. Inspecting general equilibrium conditions implies that consumption, physical capital, wages, real deposits and collateral government bonds grow at the technology growth rate, i.e. $c_t/c = K_{t+1}/K = w_t/w = b_{t+1}^h/b^h = b_{t+1}^b/b^b = (1+\gamma)^t$. On the other hand, Lagrange multipliers on budget constraint and real production shrink at growth rate, i.e. $\lambda_t/\lambda = \xi_t/\xi = (1+\gamma)^{-t}$. Finally, employment in various sectors and price variables remain invariant, i.e. $n_t/n = m_t/m = \tilde{m}_t/\tilde{m} = R_t^T/R^T = R_t^L/R^L = R_t^{IB,T}/R^{IB,T} = R_t^{IB}/R^{IB} = R_t^B/R^B = R_t^D/R^D = P_t = q_t = 1$. Substituting for the balanced growth evolution of variables in the general equilibrium conditions yields balanced-growth equilibrium conditions.

$$\frac{\phi}{c\lambda} = 1 + \frac{1}{V}\left(\frac{R^T - R^D}{1 + R^T}\right) \tag{1.9.1}$$

$$\frac{1}{1+R^T} = \frac{\beta}{1+\gamma} \tag{1.9.2}$$

$$\frac{1-\phi}{1-n-m-\tilde{m}} = w\lambda \tag{1.9.3}$$

$$w = \frac{1-\eta}{\mu}\left(\frac{K}{(1+\gamma)n}\right)^{\eta} \tag{1.9.4}$$

$$R^T - R^K = k\left(R^T - R^{IB,T}\right) F\alpha\left(\frac{m}{b^h + kK}\right)^{1-\alpha} \tag{1.9.5}$$

$$R^T - R^B = \left(R^T - R^{IB,T}\right) F\alpha\left(\frac{m}{b^h + kK}\right)^{1-\alpha} \tag{1.9.6}$$

$$R^{IB,T} - R^B = \frac{1}{\ell}\left((1-rr)R^{IB,T} - R^D\right) \tilde{F}\tilde{\alpha}\left(\frac{\tilde{m}}{b^b}\right)^{1-\tilde{\alpha}} \tag{1.9.7}$$

$$w = \left(\frac{R^T - R^{IB,T}}{1+R^T}\right) F(1-\alpha)\left(\frac{b^h + kK}{m}\right)^{\alpha} \tag{1.9.8}$$

$$w = \frac{1}{\ell}\left(\frac{(1-rr)R^{IB,T} - R^D}{1+R^T}\right) \tilde{F}(1-\tilde{\alpha})\left(\frac{b^b}{\tilde{m}}\right)^{\tilde{\alpha}} \tag{1.9.9}$$

$$\left(\frac{K}{1+\gamma}\right)^{\eta} n^{1-\eta} = c + K\left(1 - \frac{1-\delta}{1+\gamma}\right) \tag{1.9.10}$$

$$b^h + b^b = \bar{b}\, c \tag{1.9.11}$$

$$VD = c \tag{1.9.12}$$

$$F\left(b^h + kK\right)^{\alpha} m^{1-\alpha} + b^b = (1-rr)D \tag{1.9.13}$$

$$\tilde{F}\left(b^b\right)^{\tilde{\alpha}} \tilde{m}^{1-\tilde{\alpha}} = \ell D \tag{1.9.14}$$

$$R^L = (1-\alpha)\, R^T + \alpha\, R^{IB,T} \tag{1.9.15}$$

$$R^{IB} = \left(1 - \frac{\tilde{\alpha}}{\ell}(1-rr)\right) R^{IB,T} + \frac{\tilde{\alpha}}{\ell} R^D \tag{1.9.16}$$

where markup is denoted by $\mu = \frac{\theta}{\theta-1}$ and

$$1 + R^K = 1 - \delta + \frac{\eta}{\mu}\left(\frac{(1+\gamma)n}{K}\right)^{1-\eta}$$

The set of 16 equations (1.9.1) to (1.9.16) determine the balanced-growth values of c, w, K, λ, n, m, e, D, b^h, b^b, R^T, R^L, $R^{IB,T}$, R^{IB}, R^B and R^D.

1.10 Calibration and Initial Quantitative Assessment

Now, we show there exists a plausible calibration of the parameters of the model that matches average observables of the US economy.

1.10.1 Calibration

The sample period used for calibration of parameters includes data before the financial crisis of 2007, which is quarterly data from 1971Q1 till 2006Q4 (pre-crisis period) of US economy.

Table 1.1: Parameter values calibrated with outside data directly

Symbol	Value	Description
ϕ	0.4	Share of consumption in household's utility function
η	0.36	Share of capital in goods production
γ	0.005	Productivity growth rate, quarterly
β	0.99	Discount factor, quarterly
δ	0.025	Depreciation rate, quarterly
μ	1.1	Markup
V	0.48	Velocity of deposit circulation, quarterly
rr	0.005	Reserve ratio
$\bar{b}$	0.92	Average government bond collateral relative to quarterly GDP

The model has 15 parameters that need to be specified. These parameters are calibrated in two ways exhibited in Tables 1.1 and 1.2. Table 1.1 displays the values of 9 parameters that are directly chosen. The first six parameters in this table appear in conventional NNS models without money and banking and their values are set according to the choice of GM. The three remaining parameters pertain to the money and banking sector and they are set according to data. A bank in the model is assumed to stand for a 'depository institution' in the data. As a result, bank deposits are measured by the contribution of depositories to M3. The velocity parameter, V, is accordingly the ratio of quarterly GDP to bank deposits.

Table 1.2: Jointly calibrated parameters of the model to match six observables

Symbol	Value	Description
α	0.60	Share of collateral in household loan production
F	22	Productivity of household loan production
k	0.017	Productivity of capital collateral relative to bond collateral
$\tilde{\alpha}$	0.20	Share of collateral in interbank loan production
$\tilde{F}$	144	Productivity of interbank loan production
ℓ	0.65	Average gross interbank loans relative to deposits

A key parameter in the model is $\bar{b}$ that captures the supply of government debt relative to quarterly GDP. The paper includes Treasuries and GSEs as government bonds

Table 1.3: Comparison of average values of observables over the sample to model-implied endogenous variables

Variable	Value	Model output	Description
R^B	1.38%	1.22%	Real government bond rate
$R^{IB} - R^B$	1.03%	1.05%	The TED Spread
$R^L - R^{IB}$	2.00%	1.82%	Collateralized External Finance Premium
$\frac{m+\tilde{m}}{m+\tilde{m}+n}$	1.44%	1.54%	Share of banking employment in total employment
B^b/D	21.37%	21.28%	Banking holding of government bonds relative to deposits
R^D	1.28%	1.11%	Average deposit rate on all deposits

Table 1.4: Remaining model-implied endogenous variables under the benchmark calibration

c	n	K	w	λ	R^{IB}	b^h
0.8181	0.3323	8.9313	1.8993	0.4768	0.0057	0.3900
R^B	R^L	$R^{IB,T}$	m	b^b	$\tilde{m}$	R^D
0.0031	0.0102	0.0070	0.0023	0.3626	0.0029	0.0028

and excludes non-collateral holding of government debt as explained in the data section of the appendix. Note, however, that the paper does not distinguish between the maturities of various government bonds as it restricts attention to balanced growth path equilibrium, along which relative prices of various maturities are constant.

Table 1.2 displays six parameters that govern the activities of banks in the model, which are jointly chosen to match as closely as possible to underlying money and banking observables. Specifically, calibration of banking parameters seeks to match average values for the following variables over the sample period: a) the short-term government bond rate, b) the external finance premium, c) employment in the banking sector, d) the TED spread, e) share of government bonds on the balance sheet of banks, and f) the deposit rate. Table 3.2 shows that model-implied and observable variables match fairly well. Description of data sources and calculation of the observable variables from the data is presented in the appendix.

1.10.2 Initial Quantitative Assessment

The values of banking parameters displayed in Table 1.2 illuminates general features of the money and banking sector in several ways. It specifically sheds light on the difference between loans to households and interbank loan technologies, composition of total collateral and the role for capital collateral, and the estimated size of interbank market.

The parameters α and $\tilde{\alpha}$ govern the share of collateral in loan technologies in the loan to households and interbank loan markets. Calibration results suggest that the interbank loans are more monitoring-intensive, while loans to households are more collateral-intensive marked by α three times as large as $\tilde{\alpha}$. Interbank loans are typically characterized by high frequency with short maturity that makes them a suitable means for banks to facilitate transaction services. Note also that government debt on the banks balance sheet serves collateral services without being explicitly pledged and as a result has relatively less marginal collateral value to banks than households. In line with these considerations, calibration finds that the productivity of interbank credit, $\tilde{F}$, is quite larger than productivity of loans to households, F. The above discussion implies the parameter values make intuitive sense.

Total collateral is composed of capital collateral (only available to household loans) and government collateral. The calibration suggests a very small collateral productivity of capital relative to government debt captured by parameter k. This could be explained by noting that the capital in the model includes capital goods belonging to corporations who finance their liquidity demand by issuing corporate bonds and equities in the stock market. As a result while their capital stock economizes on financing costs, it does not offer collateral services against bank loans and it is therefore not measured by k.

The value of k reveals composition of collateral assets in the economy. Total supply of collateral relative to consumption is evaluated by $\bar{b} + k\frac{K}{c}$ in the model. Table 1.4 shows the solution of remaining variables under the benchmark calibration. The balanced growth solution for quarterly capital to consumption ratio is 10.9, which implies capital collateral is 0.18 versus government collateral that is 0.92 relative to quarterly GDP. Noting that banks absorb almost half of government bonds on average, capital collateral accounts for 30% of household collateral. This suggests that the value of k is relatively substantive.

How does the collateral composition compared with GM paper? According to their calibration $k = 0.20$, which implies capital collateral is 2.19, while government collateral is 0.56 (relative to quarterly GDP). Therefore, capital collateral accounts for 80% of total collateral in GM's calibration. Remember that unlike this paper, banks are not allowed to absorb government collateral in their framework. The total weighted household collateral is therefore equal to 2.75 in GM paper compared with 0.65 in this paper. As a result, banks turn out to be more productive in this paper compared with GM who find $F = 9$. This observation clearly highlights the modeling differences of allowing banks to hold and receive collateral services from government debt on their balance sheet made in this paper.

The relative collateral value of capital has important analytical implications for the interaction between the money and banking sector and the real sector on the balanced growth path. With a small k in the model, changes in the money and banking sector (e.g. due to a banking shock) affect the real sector only insignificantly on the balanced growth path. This result follows by noting that capital collateral services yield is equal to k times government collateral services yield[10]. The effect on capital stock due to changes in the money and banking sector in the model is implied by changes in the capital collateral services yield, which is quite small resulting in a quite small effect.

Finally, the calibrated value of aggregate gross interbank credit relative to deposits, ℓ, implies that in order to provide transaction services for any dollar of deposits that a bank produces, it would on average expect to borrow 65 cents of interbank credit during a period.

1.11 Market for Collateral Services

Before turning to the quantitative implications of the full model for various policy exercises, it is helpful to describe how the market for collateral services works to satisfy uniform pricing of collateral services by households and banks and hence the collateral allocation in the economy.

Using the baseline calibration, the market for collateral services is analyzed by distinguishing between demand and supply for collateral services. Note, however, that in the model collateral services are demanded by households and banks and the supply of government debt collateral is governed by fiscal authority. Therefore, in order to characterize determination of economy-wide collateral services yield in equilibrium, the intersection of banking demand for collateral and the total supply of collateral net of household absorption of collateral is studied.

1.11.1 Theory

The *aggregate demand for banking collateral* shows the internal valuation of government debt held by banks on their balance sheet. It represents the aggregate demand for government bonds by banks at a given collateral services yield of government debt to banks, which follows[11],

$$\frac{B^b}{D} = \frac{(\ell)^{\tilde{\alpha}}}{\tilde{F}} \left(\left(\ell - \frac{B^b}{D} \right) \frac{\tilde{\alpha} w}{(1-\tilde{\alpha})\left(R^{IB} - R^B\right)} \right)^{1-\tilde{\alpha}} \tag{1.11.1}$$

Equation (1.11.1) shows that aggregate banking demand for holding government debt relative to deposits is decreasing with respect to $R^{IB} - R^B$, i.e. the TED spread. Moreover, banks demand for government debt (as a ratio of deposits) increases as a result of two factors: a) a decline in the general productivity of interbank credit extension captured by a smaller $\tilde{F}$, and b) a less efficient provision of transaction services that requires higher interbank credit for servicing deposits captured by a larger ℓ.

[10] Conditions (1.9.5) and (1.9.6) imply $R^T - R^K = k(R^T - R^B)$.

[11] Derivation of relations in this section is presented in the appendix.

From the banking perspective, the *aggregate supply of banking collateral*, accounts for the aggregate supply of government bonds net of absorption of households, which is expressed as following,

$$\frac{\bar{b}\,V + k\frac{K}{c}V - \frac{B^b}{D}}{1 - rr - \frac{B^b}{D}} = \frac{1}{F}\left(\frac{\alpha w}{(1-\alpha)\left(R^T - R^B\right)}\right)^{1-\alpha} \tag{1.11.2}$$

Equation (1.11.2) is specified in terms of the household collateral services yield. The opportunity cost of banking collateral and the household collateral services yield are connected according to,

$$R^{IB} - R^B = \left(1 - \frac{1}{\ell}\frac{B^b}{D}\right)\left(\left(R^T - R^B\right) - \frac{1}{F}\left(\frac{w}{1-\alpha}\right)^{1-\alpha}\left(\frac{R^T - R^B}{\alpha}\right)^{\alpha}\right) \tag{1.11.3}$$

Equations (1.11.2) and (1.11.3) together express the supply of government debt in terms of its opportunity cost to banks, and demonstrates an increasing relationship between government bonds supplied to banks and the TED spread. Accordingly, banking collateral supply is determined by two major components: the total supply of collateral, and the household demand for collateral. A decline in the total supply of collateral (composed of government bond collateral and capital collateral) elevates the opportunity cost of banking collateral. As a result, a general reduction in the supply of government debt relative to aggregate output captured by a smaller $\bar{b}$ in the model results in large movements in the banking collateral supply curve. Moreover, an adverse shock to productivity of loans to households captured by a smaller F also results in marginally more expensive supply of collateral to banks.

Consequently, general pricing of collateral services is determined when the aggregate demand for banking collateral coincides with the supply of banking collateral[12], thereby equating collateral valuation from banks and households perspectives.

1.11.2 Under Calibration

Using baseline calibration, annualized banking internal valuation of collateral in terms of relative share of government debt on their balance sheet is,

$$TED = \frac{0.65 - \frac{B^b}{D}}{\left(\frac{B^b}{D}\right)^{1.25}} \times 34 \tag{1.11.4}$$

Similarly, the model generates a supply curve for banking collateral services us-

[12]In the specification of collateral supply and demand it is important to note that changes in the money and banking sector affect the real sector only insignificantly due to a small value for k.

ing baseline calibration that shifts as the supply of government debt relative to GDP changes. These two curves along with observed data are displayed in Figure **??**. The graph shows a reasonably well fit between the model implied curve and location of data points. Note that the model implies as the supply of government debt in the economy changes, the demand curve remains unchanged while the supply curve moves around. This coincides with the observation of government debt supply values, and thus pins down a reasonably well-behaved demand for banking collateral as illustrated by Figure **??**.

1.12 Quantitative Policy Exercises in the Full Model

Finally, using the calibrated model, this section evaluates three policy exercises[13]: (a) increase in supply of government debt collateral, (b) increase in supply of bank reserves, and (c) open market purchase of government debt in exchange for bank reserves. The first exercise is used to compare the quantitative relevance of the model to an empirical finding by Krishnamurthy and Vissing-Jorgensen (2012). The open market purchase of government debt is a combination of the previous other exercises in opposite directions.

1.12.1 Government Collateral Supply

This exercises compares balanced growth equilibria with different values of government debt relative to GDP, captured by $\bar{b}$ in the model, illustrated in Figure 1.3. The top row of Figure 1.3 displays government debt allocation between households and banks relative to GDP (left), banking collateral demand (middle) and household collateral demand (right). The bottom row displays decomposition of marginal cost of issuing and servicing deposits (left) and various interest rates in the model (right).

How does the transmission mechanism of an increase in the government debt supply work in the model? Figure 1.3 shows that starting from a scarce collateral supply ($\bar{b} < 0.95$), as the government debt supply increases both households and banks increase their holding of government debt. However, when collateral supply is abundant ($\bar{b} > 0.95$), households decrease their holding of government debt while banks holds larger government debt. To see why this happens, note that higher government debt holding by banks implies smaller bank loans issued to households due to the balance sheet constraint. In other words, the composition of banking balance sheet shifts with the same amount of deposit creation. Larger government debt on the balance

[13] Note that all of these exercises are in effect comparative statics studies on balanced growth path. On the balanced growth equilibrium, the total yield is determined independently from policy actions and thus the central bank cannot conduct its interest rate policy anymore, and it should accept the neutral interbank rate for stabilization of inflation.

sheet of banks is beneficial for banks for two reasons. By making the composition of the balance sheet safer, banks could acquire interbank credit at better rates (saving on servicing deposits). Moreover, they extend smaller loans to households and thus save on external finance premium costs (saving on issuing deposits). Smaller loan creation to households not only economizes on monitoring effort by banks but also releases household collateral. This effect works in the opposite direction to the initial increase in government debt collateral demand by households, which explains the above implication.

The quantitative implications of the exercise on rate spreads for a reduction in government debt supply relative to GDP from 0.90 to 0.60 (shown in Figure 1.3) are as follows. The transaction services yield increases by 185 basis points which is composed of: an increase of 150 basis points in the external finance premium (creating deposits) and an increase of 35 basis points in the marginal cost of transaction provision (servicing deposits). Moreover, the TED spread goes up by 260 basis points and the household collateral services yield goes up by 420 basis points.

Comparison with Krishnamurthy and Vissing-Jorgensen (2012)

To evaluate empirical relevance of the calibrated model against a benchmark, results of the exercise is compared to Krishnamurthy and Vissing-Jorgensen (2012) (K-V) who conduct an empirical study in which they examine the relation between the aggregate government debt relative to GDP and various Treasury yield spreads. They provide econometric evidence to support that the supply of Treasuries relative to GDP is a defining explanatory variable for the rate spreads. According to K-V, one standard deviation reduction in the supply of Treasuries (as a ratio of GDP) during 1984 to 2008 results in an increase of 111 basis points in the FDIC-insured CD–T-bills spread (counterpart of the TED spread in the present research), which indicates pricing of liquidity by investors.

Using baseline calibration, one standard-deviation decrease in the supply of government bonds relative to consumption from its mean value (from $\bar{b} = 0.92$ to 0.68), raises the TED spread by 164 basis points that is roughly close to their estimate. The discrepancy between the results could be explained by noting that K-V's study excludes the more volatile period of 1970s. Moreover, the regression model of K-V is linear by structure, whereas the association between government debt supply and spreads are non-linear[14]. See Figure 1.3 for implications of the policy for money and banking variables of the model.

[14] As a consequence, while a symmetric increase in government debt supply yields the same changes in the spread according to K-V, our model implies the spread would only decrease by 64 basis points.

1.12.2 Aggregate Bank-reserve Supply

Another quantitative exercise that this research studies by using the calibrated model is to compare balanced growth equilibria with different values of bank reserves supply[15] relative to total deposits, rr. Figure 1.4 displays the consequences of this exercise for various money and banking variables and interest rates in the model.

How does the transmission mechanism of higher bank reserves work in the model? In an equilibrium with higher reserve ratio, a larger fraction of assets is composed of reserves and the combination of government debt and loans to household on the balance sheet is smaller. The immediate effect of the policy is that households use reserves to pay back loans to banks, and as a result, loans on the balance sheet of banks go down to substitute with new reserves (up to the new reserve ratio). As a consequence of smaller bank loan to households, household collateral becomes relatively more abundant, resulting in smaller household collateral services yield ($R^T - R^B$). Therefore, households sell government debt to banks who now value government debt more. Higher government debt on the balance sheet of banks has two opposing effects: (a) a further reduction in loans to households due to the balance sheet constraint, and (b) an equal value of reduction in the household government collateral. Because the loan to value of household collateral is always larger than one, the second effect is stronger implying a net contraction of relative value of household collateral to loan, which alleviates the initial reduction in the household collateral services yield until equilibrium holds. In sum, the net effect is government debt held by households go down and by banks go up with an equal reduction in bank loans to households.

Note that because banks produce smaller loans in the new equilibrium, the external finance premium gets smaller, which is reflected by a higher interbank rate in the balanced growth equilibrium[16]. This implies larger opportunity cost of holding reserves by banks, as reserves pay no interest. This effect works in the opposite direction to the smaller marginal cost of accessing interbank loans because of higher government debt holding on the balance sheet. Figure 1.4 shows that the net effect is higher opportunity cost of servicing deposits (MC^{Tr} is slightly increasing in the lower left chart).

For a quantitative sense of the exercise, let's consider an increase in the reserve ratio from 0.005 (baseline calibration) to 0.15. As a result, the transaction services yield remains unchanged which is composed of two opposing changes: a reduction of 35 basis points in the external finance premium (creating deposits) and an increase of 35 basis points in the marginal cost of transaction provision (servicing deposits).

[15] It is assumed that banking demand for reserves goes up as the supply of reserves increase, otherwise the effect of injecting higher reserves is inflationary without any change in the reserve ratio. In this paper, banking demand for reserves is assumed to have the simplest form given by (1.2.4).

[16] Remember that the total yield remained unchanged as a result of the policy. Therefore smaller spread essentially implies higher interbank rate.

Moreover, the TED spread goes down by 45 basis points and the household collateral services yield goes down by 80 basis points.

1.12.3 Open Market Purchase of Government Debt

Finally, the calibrated model is used to evaluate quantitative consequences of equally higher bank reserves and smaller government debt[17], which is intended to replicate open market purchase of government debt. The policy is in fact combination of previous two exercises. Results are displayed in Figure 1.5 for balanced growth equilibria with various sizes of reserve ratio and government debt supply.

How does the transmission mechanism work in this quantitative exercise according to the model? Suppose initially the central bank purchases government bonds from households in exchange for reserves who use the proceeds to pay back their loans to banks. As a result, both loans and household collateral go down by equal values. Because the loan-to-value ratio is larger than one, the net effect causes the loan-to-value ratio to increase[18] and creates a net scarcity of collateral, thereby causing the household collateral services yield to rise. Accordingly, the opportunity cost of banking collateral goes up, which motivates banks to sell government bonds to households and hold less bonds on their balance sheet. Therefore, both of external finance premium and marginal cost of transaction services provision rise implying a costlier money and banking sector in the economy. In this sense, the policy creates a contraction in the economy. Quantitatively, comparison of a balanced growth equilibrium with reserve ratio of 0.15 and government debt supply of $\bar{b} = 0.60$ with benchmark calibration, i.e. reserve ratio of 0.005 and $\bar{b} = 0.90$ implies the following changes in valuation of collateral and banking services. The transaction services yield increases by 130 basis points, which is composed of an increase of 80 basis points in the external finance premium (creating deposits) and an increase of 50 basis points in the marginal cost of transaction provision (servicing deposits). Moreover, the TED spread goes up by 125 basis points and the household collateral services yield goes up by 215 basis points. In sum, the policy implies higher valuation of collateral by banks and households and higher cost of issuing and servicing deposits by banks.

1.13 Concluding Remarks

The paper contributes to the literature of macroeconomic models with costly money and banking by developing a model that explains the observed short-term spread

[17]to apply netting to zero, $\Delta H + \Delta B = 0$ needs to hold. Since, $\Delta H = \Delta rr \times D$, $\Delta B = \Delta\bar{b} \times c$ and $c = V \times D$, it follows that $\Delta rr + V \times \Delta\bar{b} = 0$ satisfies the netting condition.

[18]In mathematical terms, if the inequality $\frac{a}{b} > 1$ holds, then for a positive x, it follows that $\frac{a}{b} < \frac{a-x}{b-x}$.

between the interbank rate and the government bond rate (the TED spread). In the model, costly servicing of deposits via interbank loans motivates banks to demand government debt to hold on their balance sheet. In equilibrium, the government bond rate falls below the interbank rate by collateral services valuation by banks. Moreover, the model shows how interest rate spreads are associated with costly issuing and servicing deposits by banks.

The model is shown to have a plausible calibration for the U.S. economy, which is used to evaluate quantitative performance and consequences of the model. The benchmark calibration shows a reasonable performance compared with the empirical study by Krishnamurthy and Vissing-Jorgensen (2012). Finally, the calibrated model implies that on the balanced growth path, open market purchase of government debt results in more expensive money and banking and thus contraction in the economy.

The paper develops a simple and nice foundation that could be extended in various directions to address many other interesting questions regarding costly functioning of money and banking. First, the model studies a period of no interest on reserves in which reserves are held at minimum. However, central banks have recently adopted interest on reserves policy, although the rates are quite low due to the prevailing conditions. Moreover, the model only considers a single maturity for government debt (short-term government debt) for tractability. To evaluate policy exercises that replicate quantitative easing or operation twist, the model needs to include long-term government debt, as well. In the same vein, from a measurement perspective, the supply of collateral assets could be revised by weighting various types of securities that offer collateral services, such as GSEs and private issued safe assets. Finally, the model simplifies away the non-bank money market from production of monetary services. To make the model more realistic and capture consequences of shock to this sector, the model could be extended by incorporating non-bank money market.

Appendices

Appendix A

A.1 Representative household's Lagrangian

The representative household's problem is to maximize its expected lifetime utility function subject to the five constraints (3.2.2), (2.1.6), (2.1.8), (3.2.3), and (3.2.4). Therefore, the typical household has the Lagrangian expression,

$$\begin{aligned}
\mathscr{L}_0 = {} & E_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(c_t) + (1-\phi) \log(1 - n_t^s - m_t^s - e_t^s)] + \nu_t \left(\frac{D_t^d}{P_t^A} - \frac{1}{V} c_t \right) \\
& + \Psi_t \left(F \left(b_{t+1}^h + k q_t K_{t+1} \right)^{\alpha} (A_t^m m_t^d)^{1-\alpha} + b_{t+1}^b - (1-rr) \frac{D_t^s}{P_t^A} \right) \\
& + \psi_t \left(F' \left(b_{t+1}^b \right)^{\alpha'} \left(A_t^e e_t^d \right)^{1-\alpha'} - \ell \frac{D_t^s}{P_t^A} \right) + \lambda_t \Bigg[\Bigg(\frac{D_t^s}{P_t^A} + \frac{D_{t-1}^d}{P_t^A} (1 + R_{t-1}^D) + q_t (1-\delta) K_t \\
& + \frac{1 + R_{t-1}^B}{1 + \pi_t} b_t^h + \frac{1 + R_{t-1}^B}{1 + \pi_t} b_t^b + \frac{rr}{1 + \pi_t} \frac{D_{t-1}^s}{P_{t-1}^A} + w_t (n_t^s + m_t^s + e_t^s) + c_t^A \left(\frac{P_t}{P_t^A} \right)^{-(\theta-1)} \Bigg) \\
& - \left(\frac{D_t^d}{P_t^A} + \frac{D_{t-1}^s}{P_t^A} (1 + R_{t-1}^D) + q_t K_{t+1} + b_{t+1}^h + b_{t+1}^b + rr \frac{D_t^s}{P_t^A} + w_t (n_t^d + m_t^d + e_t^d) + \tau_t + c_t \right) \Bigg] \\
& + \xi_t \left(K_t^{\eta} \left(A_t^n n_t^d \right)^{1-\eta} - c_t^A \left(\frac{P_t}{P_t^A} \right)^{-\theta} \right)
\end{aligned} \tag{A.1.1}$$

A.2 Data

The sample period is 1971Q1 to 2006Q4. Data sources and calculation of observable variables are discussed in this section.

The data for interest rates are obtained from Table H.15 of the federal reserve board of governor's website except that the interest on other checkable deposits in calculation of the average deposit rate (described below) is obtained from Center for Financial Stability website. All rates are reported per annum in this section.

The three-month Eurodollar deposit rate data is used for the interbank rate in the model, which is on average 6.98% for the sample period (1971-2006). The three-month T-bill rate data is used for the government bond rate, which is on average 5.95% implying an average spread of 103 basis points with the three-month Eurodollar rate, which gives the TED spread in the model. The CPI inflation rate (on average 4.56% during the sample period) is utilized to transform the nominal bond rate into real bond rate, which is 1.38%.

In order to find the observable external finance premium (collateralized external finance premium in the model), several alternatives have been suggested in the literature[1] but none seems to be a successful representation. To conform with GM, the spread between the prime rate and the interbank rate is used in this paper. Nevertheless, the data for prime rate–fed funds rate spread does not represent the concept of external finance premium well in the whole sample. Specifically, it has negative values in the early 1970s, while it should capture the marginal cost for loan production, which cannot be negative. In addition, this spread remains persistently at a tight neighborhood of 3% after mid 1990s implying manipulation by banks rather than reporting the true prime rate given changing lending circumstances in this period.

The deposit rate in the model represents the return on all deposits created by banks, including transaction, savings and time deposits. To evaluate the weighted average interest opportunity cost of deposits the return for other checkable deposits, one-month CD rate and three-month CD rate are weighted by the share of each deposit type. Average nominal returns for the other checkable deposits (CFS data), one-month CD rate and three-month CD rate are respectively 2.89%, 6.58% and 6.68% over the sample. The share of transaction deposits, savings deposits and time deposits in total deposits created by depositories according to Table H.6 of the federal reserve board of governors are 21%, 34% and 45% respectively. As a result, the average nominal deposit rate is 5.85%, and the real deposit rate is 1.28%.

The broad money in the model is measured by the contribution of depositories to M3 data (Table H.6 and CFS data for the year 2006), which includes demand deposits, other checkable deposits, traveler's checks, small and large-denomination time deposits at commercial banks and thrifts and savings deposits. The velocity parameter is accordingly the ratio of total deposits to quarterly GDP, which is on average equal to 0.48.

The size of the employment in the money and banking sector in the economy is measured by the share of employment by depositories in total non-farm employment. The data is obtained from the bureau of labor statistics but it is only available from 1990. The share is nonetheless quite stable around 1.44%.

The value of government bond collateral is the economy is calculated using the Flow of Funds data. The government bond collateral includes Treasuries and GSEs (Tables L.209 and L210 in the Flow of Funds) held by households and banks. The household government debt holding includes the holdings by the household sector, the non-financial corporate business and the mutual funds in the Flow of Funds. The banking government debt holding includes the US-chartered depository institutions, foreign banking offices in the US, banks in US-affiliated areas and Credit Unions. Other holdings of government debt including government, foreign, insurance and money markets are excluded because they are not used as collateral against banking services in the sense the paper studies. As a result, the total supply of government debt relative to quarterly GDP is 0.92, with the household holding relative to

[1] Look at De Graeve (2008).

quarterly GDP equal to 0.49 and the banking holding relative to quarterly GDP equal to 0.43. The banking holding relative to deposits is on average equal to 21.37%.

A.3 Derivation of demand and supply for collateral services

The section shows how the aggregate demand and supply of banking collateral services are derived from the equilibrium conditions.

A.3.1 A. Banking Collateral Demand

Use (2.1.9) and (1.4.6),

$$\frac{R_t^{IB,T} - R_t^B}{1 + R_t^T} = \frac{\psi_t}{\lambda_t}\tilde{\alpha}\left(\frac{L_t^b/P_t^A}{b_{t+1}^b}\right) \tag{A.3.1}$$

Moreover, rewriting (1.6.10),

$$\frac{R_t^{IB} - R_t^B}{1 + R_t^T} = \frac{\psi_t}{\lambda_t}\tilde{\alpha}\left(\frac{L_t^b/P_t^A}{b_{t+1}^b} - 1\right) \tag{A.3.2}$$

Therefore,

$$R_t^{IB,T} - R_t^B = \frac{1}{1 - \frac{1}{\ell}\left(\frac{b_{t+1}^b}{D_t/P_t^A}\right)}\left(R_t^{IB} - R_t^B\right) \tag{A.3.3}$$

Equation (A.3.3) expresses the TED spread in terms of the unobservable TED spread.

On the other hand, divide (1.6.5) by (1.6.6),

$$\frac{\tilde{m}_t}{b_{t+1}^b} = \frac{(1-\tilde{\alpha})\left(\frac{R_t^{IB,T} - R_t^B}{1+R_t^T}\right)}{\tilde{\alpha} w_t} \tag{A.3.4}$$

Using (A.3.4) in interbank loan technology (2.1.9) and (2.1.8) gives

$$\frac{b_{t+1}^b}{D_t/P_t^A} = \frac{\ell}{\tilde{\bar{F}}}\left(\frac{\tilde{\alpha}}{1-\tilde{\alpha}}\frac{w_t/A_t^{\tilde{m}}}{\left(\frac{R_t^{IB,T} - R_t^B}{1+R_t^T}\right)}\right)^{1-\tilde{\alpha}} \tag{A.3.5}$$

Equation (A.3.5) expresses banking demand for government bonds relative to deposits in terms of the relative opportunity cost of monitoring and banking collateral service yield. Apply (A.3.3) in (A.3.5),

$$\frac{b_{t+1}^b}{D_t/P_t^A} = \frac{\ell}{\tilde{\bar{F}}}\left(\frac{\tilde{\alpha}}{1-\tilde{\alpha}}\left(1 - \frac{1}{\ell}\frac{b_{t+1}^b}{D_t/P_t^A}\right)\frac{w_t/A_t^{\tilde{m}}}{\left(\frac{R_t^{IB} - R_t^B}{1+R_t^T}\right)}\right)^{1-\tilde{\alpha}} \tag{A.3.6}$$

Equation (A.3.6) demonstrates the aggregate banking demand for collateral services. (1.11.1) is the balanced growth version of this equation.

A.3.2 B. Banking Collateral Supply

The household demand for collateral services in the model along with the total supply of government bonds in the economy are integrated in what is called the banking collateral supply. The total supply of government bonds are determined by government's fiscal policy. Therefore,

$$b^b_{t+1} + b^h_{t+1} = \bar{b}\, c_t \tag{A.3.7}$$

To find household collateral demand, first divide both sides of (1.6.1) by (1.6.2) to obtain,

$$\frac{m_t}{b^h_{t+1} + kq_tK_{t+1}} = \frac{(1-\alpha)\left(\frac{R^T_t - R^B_t}{1+R^T_t}\right)}{\alpha w_t} \tag{A.3.8}$$

Use (A.3.8) in household loan production technology (2.1.7),

$$\frac{b^h_{t+1} + kq_tK_{t+1}}{L^h/P^A_t} = \frac{1}{F}\left(\frac{\alpha}{1-\alpha}\frac{w_t/A^m_t}{\left(\frac{R^T_t - R^B_t}{1+R^T_t}\right)}\right)^{1-\alpha} \tag{A.3.9}$$

Equation (A.3.9) expresses households demand for collateral services in terms of wage and household collateral services yield.

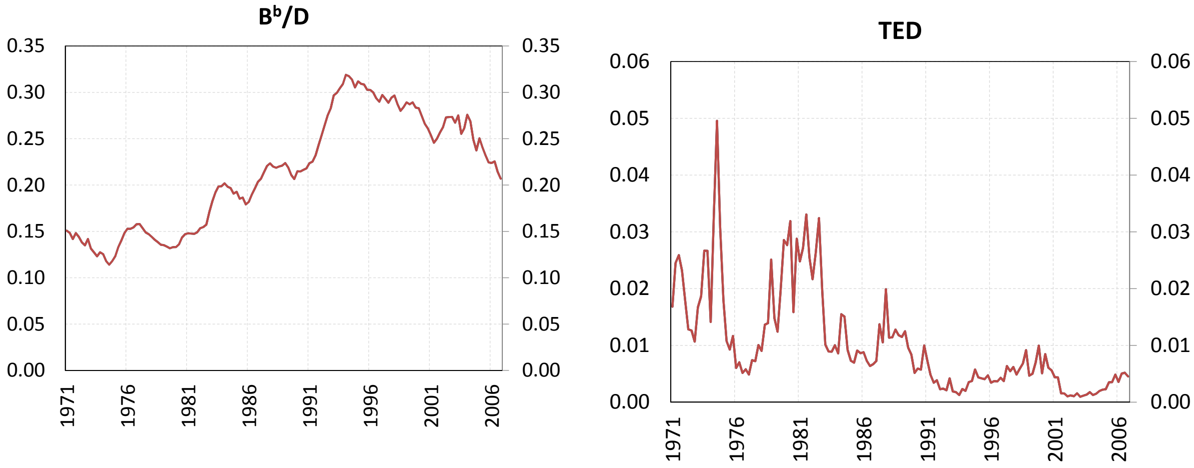
Now, to find the banking collateral supply, use (A.3.7), (2.1.6), and (3.2.2),

$$\frac{\bar{b}\,V + k\frac{q_tK_{t+1}}{c_t}V - \frac{b^b_{t+1}}{D_t/P^A_t}}{1 - rr - \frac{b^b_{t+1}}{D_t/P^A_t}} = \frac{1}{F}\left(\frac{\alpha}{1-\alpha}\frac{w_t/A^m_t}{\left(\frac{R^T_t - R^B_t}{1+R^T_t}\right)}\right)^{1-\alpha} \tag{A.3.10}$$

Equation (A.3.10) is specified in terms of household collateral services yield. Opportunity cost of banking collateral is derived from household collateral services yield, using (A.3.8) in (1.6.1) and the identity $R^{IB,T}_t - R^B_t = \left(R^T_t - R^B_t\right) - \left(R^T_t - R^{IB,T}_t\right)$. Thus,

$$\frac{R^{IB}_t - R^B_t}{1+R^T_t} = \left(1 - \frac{1}{\ell}\frac{b^b_{t+1}}{\frac{D_t}{P^A_t}}\right)\left(\frac{R^T_t - R^B_t}{1+R^T_t} - \frac{1}{F}\left(\frac{w_t/A^m_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{1}{\alpha}\frac{R^T_t - R^B_t}{1+R^T_t}\right)^{\alpha}\right) \tag{A.3.11}$$

(A.3.10) and (A.3.11) together characterize the banking collateral supply. (1.11.2) and (1.11.3) are balanced growth versions of these equations.



(a) Government Debt Holdings of Depositories relative to Deposits

(b) The 3-month TED Spread

Figure 1.1: Government Debt Holdings of Depository Institutions and the TED spread

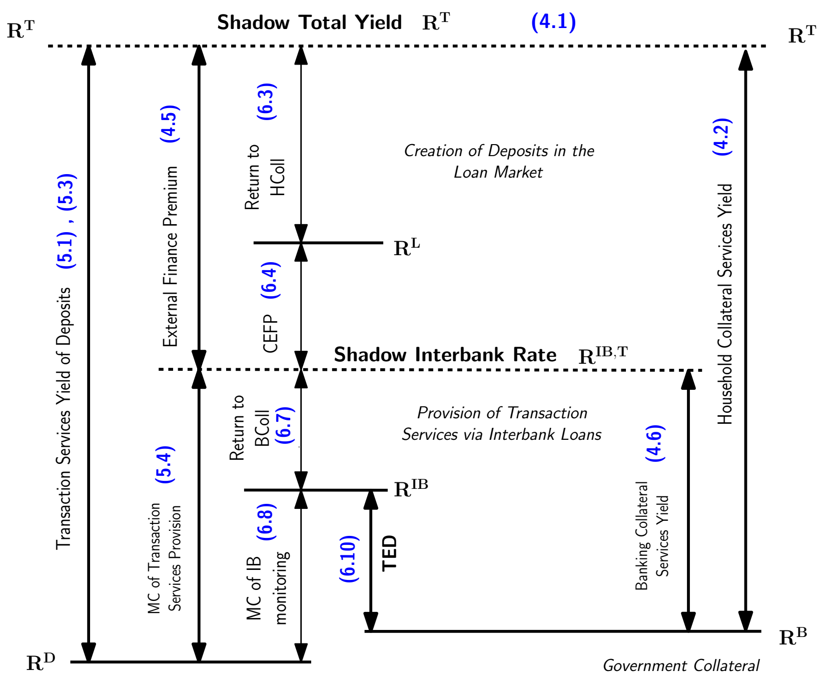


Figure 1.2: Connection between various interest rates in the model.

Note: Numbers in parentheses represent the corresponding equation in the text.

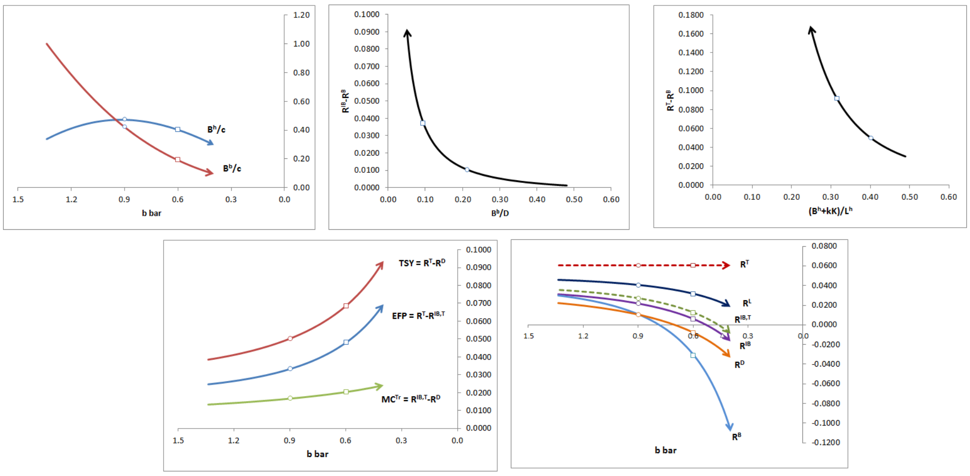


Figure 1.3: Government debt collateral policy.

Note: Balanced growth equilibria with various values for supply of government debt relative to GDP, $\bar{b}$, in the economy. One standard deviation drop in $\bar{b}$ (from circle marker to square marker).

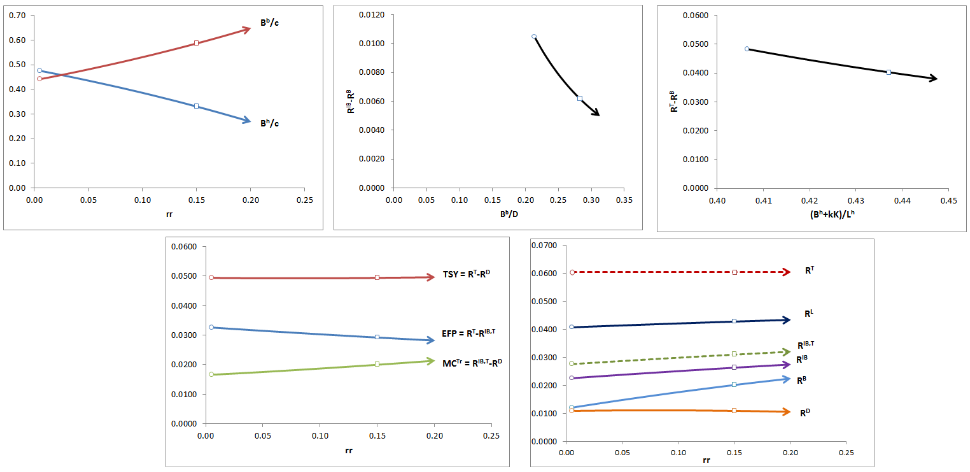


Figure 1.4: Aggregate bank-reserve supply .

Note: Balanced growth equilibria with various values for bank reserves relative to deposits, rr, in the economy. Increase in rr (from circle marker to square marker) is by equal value of reserves to the drop in value of government debt displayed in previous figure.

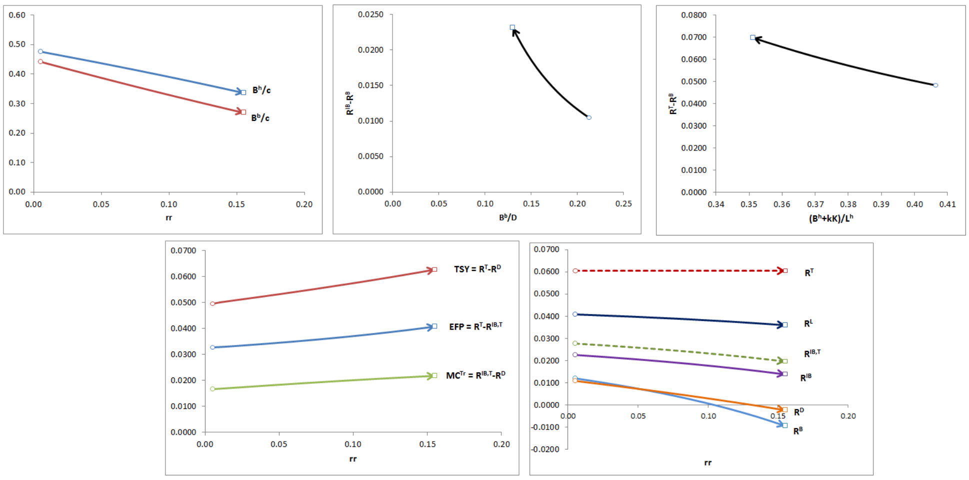


Figure 1.5: Open market purchase of government debt.

Note: The figure is combination of previous two figures. Balanced growth equilibria with higher bank reserves and equally smaller government debt supply.

Chapter 2

The TED Spread in a New Keynesian Model with Money and Banking

The three-month EuroDollar–T-Bill (TED) spread has been commonly used as an indicator of stress in the banking system. This paper studies the underlying determinants of the TED spread arising from disturbances to the loan market and the interbank market, as well as collateral supply shocks in a new Keynesian model with banking. Using observations for collateral supply and banks' balance sheet compositions in the calibrated model, TED spikes are analyzed over seven instances of banking distress. Results show that the supply of government securities relative to GDP (collateral) is an important driver of the TED spread. Moreover, scarcity of collateral raises the sensitivity of the TED spread to shocks to credit markets. Specifically, shocks to banking in the late 1990s were substantially stronger than the early 1970s, even though the TED spread elevated more sharply in the latter period. The paper concludes without accounting for collateral effects, the TED spread could inconsistently reflect the severity of banking distress.

Introduction

Banking distress gives rise to elevated cost of monetary services. Many observers from the policy and academic sectors have long regarded the three-month EuroDollar–T-Bill yield spread (famously known as "the TED spread"[1]) as an indicator of the severity of banking distress.[2] Implications of the TED spread fluctuations for banking distress

[1]Note that the three-month EuroDollar rate represents the interest cost of interbank borrowing over the three-month maturity for the U.S. banks. Otherwise, the paper is not a study of international economy.

[2] Notable examples include Timothy Geithner (2014) and the Economic Report of the President (2009) in the policy sector, as well as Brunnermier (2009) and Macroeconomics textbook by Mankiw (2012) from academia. Other examples are Filipovic and Trolle (2013), Christensen et al (2014), Boudt et al (2014) from academia, Willardson (2008) from the Federal Reserve and Investopedia among many

and in turn on the macroeconomy have not been explored in the Macro-Finance literature. Specifically, does the TED spread consistently reflect the intensity of banking stress and in particular for the purposes of the monetary policy?

The paper embeds money, bank monitoring and collateral services into an otherwise representative agent New Keynesian framework. The TED spread reflects valuation of collateral services that government securities provide to a bank in acquiring short-term funds (interbank borrowing) in order to *provide payment services* to its depositors.[3] Moreover, banks supply transaction-facilitating deposits (broad money) to households who *finance deposits* via borrowing funds from banks. As a result, there is a loan production technology involved with each function of banks based on the following principle; to extend loans, banks employ ex ante monitoring effort to avoid ex post default and collateral holdings of the borrower defrays the cost of monitoring by the lender.

The benchmark for the intensity of banking distress in the model is the spread between the shadow total yield[4] and the deposit rate, which captures the foregone pecuniary interest due to holding the transaction-facilitating asset by the household. There are four sources that contribute to costliness of banking: a) scarcity of collateral assets, b) lower productivity of monitoring households, c) lower productivity of interbank monitoring, and d) higher frequency of utilizing deposits for transaction purposes. The paper connects these dimensions of banking distress to the TED spread in the market for collateral services.

The paper's objective will then be to study seven episodes of banking distress reflected by sharply elevated TED spreads in the U.S. from 1960 to 2006.[5] The model parameters are calibrated to match averages of rate spreads and other banking observations during the sample period.

The strategy of the paper is threefold. First, I wish to investigate the implied structural changes in banking by means of the deterministic version of the model together with observations of banking and collateral supply relative to GDP. My aim in this regard is to uncover and measure banking parameters at each episode to account for trend movements in the TED spread before studying the implications of short-term

others.

[3]This approach is motivated by two observations in banking data. First, there is a relatively robust inverse relation between the TED spread and U.S. bank holdings of government securities per dollar of deposits from 1960 to 2006. Furthermore, the latter demonstrates a high correlation with the supply of government securities relative to GDP in the sample period.

[4]The shadow total yield represents the total risk-adjusted return of any asset held by the representative household in equilibrium and satisfies the standard Euler equation. Similarly, the paper defines the shadow interbank rate that represents the total opportunity cost of loanable funds to a bank.

[5]These episodes include the commercial paper crisis of 1969, banking crisis of 1974, the Volker disinflation era and second oil crisis of 1981, the 1987 stock market crash, the 1990 credit crunch, the Russian debt crisis of October 1998 and the Dot-Com bubble of June 2000. I do not study the 2008 spike in TED partly because the monetary policy regime confronted zero lower bound problem and role of large supply of bank reserves in the new situation, which are not modeled here.

spikes of the TED spread.

The second part of the paper's strategy is to log-linearize the model around the calibrated steady-state that accounts for structural changes in banking at each episode. The goal is to identify and quantify shocks emanating from banking that generate observed TED spikes and bank adjustments of collateral holdings. Further, I wish to investigate whether TED spikes consistently capture the intensity of real consequences of banking distress at each episode.

The third part of the strategy takes into consideration monetary policy response to banking distress. In particular, it investigates the desirability of the central bank to rely on the TED spread to mitigate the effects of banking distress and explores an alternative option otherwise.

Among other things, the paper finds that the sensitivity of the TED spread to banking distress significantly and negatively depends on the supply of collateral relative to GDP. As a consequence, the model predicts a low level and volatility for the TED spread in a regime with abundant government securities relative to GDP consistent with the data.[6] This result implies that without accounting for collateral supply effects, the TED spread does not consistently indicate the severity of banking stress and would be a misleading indicator for policy purposes.

The paper also finds that banking distress is characterized by deep shocks to the productivity of monitoring households and interbank monitoring that in turn impose a significant "banking services tax" on aggregate consumption. When the central bank ignores money and banking and relies on a conventional Taylor rule, fluctuations in the banking services tax produces deep recession in aggregate consumption and brings about deflation. To best mitigate these effects, the central bank should adjust its interbank rate instrument in accordance with the loan-deposit rate spread rather than the TED spread.

The paper is comprised of three main parts. The first section presents the model and develops the analytical framework. Other sections contain quantitative analysis and implement the paper's strategy. Section 2 focuses on structural changes in banking. Section 3 studies episodes of banking distress. Section 4 explores monetary policy issues. Final remarks are made at conclusion.

2.1 Model

The model incorporates a money and banking sector into a new Keynesian framework. The environment features a representative agent economy, divided over two

[6] This finding proposes an explanation for the highly volatile TED fluctuations with an elevated average during 1970s and early 1980s and much less volatile with substantially lower average over the rest of the sample.

sectors: a perfectly competitive banking sector that issues and services transaction-facilitating deposits, and a standard production sector with monopolistic competition that produces differentiated goods.

Bank deposit (money) is demanded and supplied as following. Households demand deposits to make payments during the period, which facilitate trade of goods and assets among themselves. At the beginning of each period, households learn their demand for deposits and finance their deposit demand by borrowing one-period illiquid loans from banks and selling government securities to banks. This means from a bank's view that a bank *creates deposits* by extending loans to households using its loan production technology or buying government securities at the beginning of the period. In addition, during the period a bank executes payment instructions of depositors via borrowing interbank credit (*provision of transaction services*).[7] There is accordingly an interbank loan technology by which banks extend credit to each other. A bank learns its demand for the gross amount of interbank credit to make payments at the beginning of the period.[8]

The roles for bank monitoring and collateral services appear in the loan production technologies. To ensure timely repayment of loan, a bank monitors the borrower who could in turn hold collateral assets to defray the cost of bank monitoring.[9] A household obtains collateral services from government bonds and to a lesser degree from capital. A bank receives collateral services only from government securities.

In what follows, I first describe the problems of the representative bank, household and firm. Next, I characterize the general equilibrium in the economy and then illustrate the connection between various interest rates in the model.

2.1.1 Households

There is a continuum of identical households in the economy. Households own banks and firms. Let the c_t denote household's consumption of goods, N_t^s total supply of its time to work in the production and banking sectors, D_t^d household's deposit demand from other banks than it owns, and B_{t+1}^h household holdings of government securities that matures at the beginning of period $t+1$.

The household's problem is to choose $\left(D_t^d, c_t, B_{t+1}^h, N_t^s\right)$ to maximizes its lifetime utility from consumption and leisure given the wage rate w_t, the deposit rate R_t^D, the government bond rate R_t^B, the aggregate level of prices, P_t^A, income from profits of its

[7]Since bank deposits are the only medium of exchange, a payment is essentially transfer of funds from the payor's bank to the payee's bank, hence a payment could be financed by interbank borrowing during the period.

[8]This assumption allows for solving the model at the beginning of the period and makes the analysis quite simple without much loss of generality.

[9]By choosing the safety of its asset composition, the borrower incurs less expenses to compensate for the monitoring effort of the lender.

bank and firm $\Pi_t^b + \Pi_t^f$ and lump-sum tax payment to the government τ_t,

$$\max E_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(c_t) + (1-\phi) \log(1 - N_t^s)].$$

The household's flow of funds (budget) constraint is given by,

$$\frac{D_{t-1}^d}{P_t^A}(1 + R_{t-1}^D) + \frac{B_t^h}{P_t^A} + w_t N_t^s + \Pi_t^f + \Pi_t^b \geqslant \frac{D_t^d}{P_t^A} + \frac{B_{t+1}^h}{P_t^A(1 + R_t^B)} + c_t + \tau_t, \tag{2.1.1}$$

where, the left side expresses the net wealth of the household at the beginning of period t.

In order to consume any unit of goods, the household's has to satisfy it deposit demand constraint given by,

$$\frac{D_t^d}{P_t^A} \geqslant \frac{1}{V} c_t, \tag{2.1.2}$$

where V is assumed to be a constant and specifies the velocity of deposit circulation.

Denote the Lagrange multiplier of the household's transaction demand constraint by ν_t. Accordingly, the optimal conditions for the household's choice variables D_t^d, c_t and N_t^s are given by[10],

$$\frac{\nu_t}{\lambda_t} + E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + R_t^D}{1 + \pi_{t+1}} \right] = 1 \tag{2.1.3}$$

$$\frac{\phi}{c_t \lambda_t} = 1 + \frac{1}{V} \frac{\nu_t}{\lambda_t} \tag{2.1.4}$$

$$\frac{1-\phi}{1 - N_t^s} = w_t \lambda_t, \tag{2.1.5}$$

where $\pi_{t+1} \equiv P_{t+1}^A / P_t^A - 1$ represents the inflation rate.

According to optimal deposit demand (2.1.3), ν_t/λ_t reflects household valuation of monetary services. As a result, the representative household would be willing to receive lower pecuniary return on deposits to satisfy its deposit demand constraint. Further, consumption demand (3.3.1) reveals that the foregone interest on deposits imposes an implicit tax per unit of consumption that drives a wedge between the marginal utility of consumption and income. The expression $1/V \cdot \nu_t/\lambda_t$ represents the "banking services tax" on consumption, which means that for any unit of consumption, the household needs to hold (at least) $1/V$ units of real deposits that come at an interest cost of ν_t/λ_t.

[10] I defer the optimal choice of household holdings of government securities B_{t+1}^h, to the problem of the bank. Perfect competition allows for temporarily adopting the fiction that the bank who supplies deposits to the household optimally makes the choice of loan production factors including collateral holdings by the household. This trick extremely saves on the notation and exposition of results.

2.1.2 Banks

Consider a perfectly competitive banking industry. At the beginning of each period, each bank supplies deposits D_t^s, holds government securities B_{t+1}^b and its labor demand for monitoring households m_t and interbank monitoring $\tilde{m}_t$. Banks also choose their employment of monitoring households m_t, and monitoring other banks $\tilde{m}_t$, at the beginning of each period.

The bank's problem is to choose $\left(D_t^s, B_{t+1}^b, m_t, \tilde{m}_t\right)$ given price variables and interest rates to maximize its lifetime discounted profits,

$$\max E_0 \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(\frac{D_{t+i}^s}{P_{t+i}^A} + \frac{B_{t+i}^b}{P_{t+i}^A} - \frac{D_{t+i-1}^s}{P_{t+i}^A}(1 + R_{t+i-1}^D) - \frac{B_{t+i+1}^b}{P_{t+i}^A(1 + R_{t+i}^B)} - w_{t+i}(m_{t+i} + \tilde{m}_{t+i}) \right).$$

Here the expression in the parenthesis expresses bank profits Π_{t+i}^f at period $t+i$, and $\Lambda_{t,t+i} \equiv \beta^i \lambda_{t+i}/\lambda_t$ expresses the stochastic discount factor of the representative household.

The bank deposit creation is constrained by the balance sheet equality in combination with loan to households production technology. The nominal balance sheet equality at the beginning of period t is given by,

$$D_t^s \equiv L_t^h + \frac{B_{t+1}^b}{1 + R_t^B}, \tag{2.1.6}$$

where L_t^h denotes nominal loans to households. I posit that the real loan production technology adopts a Cobb-Douglas form with monitoring effort by the bank and collateral holdings by the household as input factors,

$$\frac{L_t^h}{P_t^A} \leqslant F \cdot \left(\frac{B_{t+1}^h}{P_t^A(1 + R_t^B)} + kq_t K \right)^{\alpha} (A_t^m m_t)^{1-\alpha}. \tag{2.1.7}$$

where the expression in the first parentheses represents household's weighted collateral. A_t^m represents shock to the productivity of monitoring households.

Deposit servicing is costly for a bank because it involves bank demand for interbank credit to provide payment services. . It is plausible to assume that interbank credit demand is proportionate to bank deposits according to

$$L_t^b \equiv \ell \cdot D_t^s, \tag{2.1.8}$$

where the parameter ℓ captures the turnover of interbank credit used for executing payment instructions of depositors. A higher ℓ implies higher transaction demand per dollar of deposits by household.[11] By analogy to loans to households, I posit that the interbank loan technology follows a Cobb-Douglas functional form with the borrower bank's government bonds and interbank monitoring of lending bank as input factors,

$$\frac{L_t^b}{P_t^A} \leqslant \tilde{F} \cdot \left(\frac{B_{t+1}^b}{P_t^A (1 + R_t^B)} \right)^{\tilde{\alpha}} \left(A_t^{\tilde{m}} \tilde{m}_t \right)^{1-\tilde{\alpha}}, \tag{2.1.9}$$

where $A_t^{\tilde{m}}$ represents shock to interbank monitoring productivity.[12]

Denote Lagrange multipliers of the deposit creation and transaction services provision constraints by Ψ_t and ψ_t. Therefore, the optimal conditions for an individual bank for its choice variables D_t^s, B_{t+1}^b, m_t and $\tilde{m}_t$ are given by,

$$\frac{\Psi_t}{\lambda_t} + \ell \cdot \frac{\psi_t}{\lambda_t} + E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + R_t^D}{1 + \pi_{t+1}} \right] = 1 \tag{2.1.10}$$

$$\frac{\Psi_t}{\lambda_t} + \Omega_t^b \cdot \frac{\psi_t}{\lambda_t} + E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{1 + R_t^B}{1 + \pi_{t+1}} \right] = 1 \tag{2.1.11}$$

$$w_t = \frac{\Psi_t}{\lambda_t} \cdot F(1 - \alpha) A_t^m \left(\frac{b_{t+1}^h + k q_t K_{t+1}}{A_t^m m_t} \right)^{\alpha} \tag{2.1.12}$$

$$w_t = \frac{\psi_t}{\lambda_t} \cdot \tilde{F}(1 - \tilde{\alpha}) A_t^{\tilde{m}} \left(\frac{b_{t+1}^b}{A_t^{\tilde{m}} \tilde{m}_t} \right)^{\tilde{\alpha}}, \tag{2.1.13}$$

where $\Omega_t^b \equiv \frac{\tilde{\alpha} \, D_t/P_t}{b_{t+1}^b}$ expresses marginal product of bank collateral in interbank loans, and the real value of government securities is defined as $b_{t+1} \equiv \frac{B_{t+1}}{P_t^A(1+R_t^B)}$.

The optimal condition for deposit supply (2.1.10), reveals that the total cost of banking services is composed of valuation of deposit creation constraint Ψ_t/λ_t and deposit servicing constraint ψ_t/λ_t, which occurs ℓ times per dollar of deposits. The optimal condition (2.1.11) implies that government securities are valued by a bank for two reasons. First, the bank can save on the cost of extending loans to households to create deposits Ψ_t/λ_t. Second, government securities provide collateral services for a bank in interbank borrowing captured by $\Omega_t^b \cdot \psi_t/\lambda_t$.

Optimal conditions for monitoring effort demand (2.1.12) and (2.1.13) imply the wage determined by the labor market offsets the value of monitoring effort in the loan production process.

Perfect competition allows us to temporarily adopt the fiction that the bank optimal chooses factor utilizations in the loan production technology given market prices. In

[11] This could be thought of as higher transaction demand for trade of assets bu households.

[12] Note that the interbank borrowing problem is essentially different from the interbank lending problem where as a borrower the individual bank makes collateral choice and as a lender makes the monitoring choice. However, symmetry allows for expressing both constraints with the same relation.

particular optimal conditions for collateral demand are given by,

$$\Omega_t^h \cdot \frac{\Psi_t}{\lambda_t} + E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{1}{1+\pi_{t+1}} \right] (1 + R_t^B) = 1 \tag{2.1.14}$$

$$k\, \Omega_t^h \cdot \frac{\Psi_t}{\lambda_t} + E_t \left[\beta \frac{\lambda_{t+1}}{\lambda_t} (1 + r_{t,t+1}^K) \right] = 1, \tag{2.1.15}$$

where, $\Omega_t^h \equiv \frac{\alpha L_t^h / P_t}{b_{t+1}^h + k q_t K_{t+1}}$ represents marginal product of household collateral and $r_{t,t+1}^K$ denotes the non-collateral return to capital asset. Conditions (2.1.14) and (2.1.15) imply that the collateral services premium needs to offset the foregone pecuniary interest on the assets incurred by borrowers.

2.1.3 Firms

Firms owned by households operate in a monopolistically competitive environment as in standard new Keynesian models. Each firm optimally chooses its capital K_{t+1}, sets price of its specific goods production P_t, and labor demand n_t given aggregate demand for consumption of goods c_t^A, price of capital q_t, P_t^A and w_t.

$$\max E_0 \sum_{i=0}^{\infty} \Lambda_{t,t+i} \left(c_{t+i}^A \left(\frac{P_{t+i}}{P_{t+i}^A} \right)^{-(\theta-1)} + q_{t+i}(1-\delta) K_{t+i} - q_t K_{t+i+1} - w_{t+i} n_{t+i} \right)$$

The firm's production and sales constraint is given by,

$$K_t^\eta \left(A_t^n n_t\right)^{1-\eta} \geqslant c_t^A \left(\frac{P_t}{P_t^A} \right)^{-\theta}, \tag{2.1.16}$$

where A_t^n represents shock to the productivity of labor in goods production.

Let the Lagrange multiplier of firm's production and sales constraint be ξ_t. Therefore, optimal conditions for choice of P_t and n_t are given by,

$$\frac{\xi_t}{\lambda_t} = \frac{\theta - 1}{\theta} \tag{2.1.17}$$

$$w_t = \frac{\xi_t}{\lambda_t} (1-\eta) A_t^n \left(\frac{K}{A_t^n n_t} \right)^\eta. \tag{2.1.18}$$

Moreover, the non-collateral component of real return to capital $r_{t,t+1}^K$ is given by

$$r_{t,t+1}^K \equiv (1-\delta) \frac{q_{t+1}}{q_t} + \frac{\eta}{q_t} \frac{\xi_{t+1}}{\lambda_{t+1}} \left(\frac{A_{t+1}^n n_{t+1}}{K} \right)^{1-\eta}. \tag{2.1.19}$$

I assume net investment is zero and thus capital stock remains fixed at its steady state value.

2.1.4 General Equilibrium

An equilibrium in the economy is characterized by

1. optimal choices of banks, households and firms,
2. market clearing conditions for
   (a) bank deposits $D^s_t = D^d_t$,
   (b) consumption goods, which implies the aggregate resource constraint $K^\eta (A^n_t n_t)^{1-\eta} = c_t + \delta K q_t$,
   (c) labor $N^s_t = n_t + m_t + \tilde{m}_t$,
   (d) government securities $b_{t+1} = b^h_{t+1} + b^b_{t+1}$.
3. Symmetry in pricing across firms $P_t = P^A_t$
4. Government
   (a) budget constraint,
   $$g_t - \tau_t = \frac{B_{t+1}}{P^A_t (1 + R^B_t)} - \frac{B_t}{P^A_t}, \tag{2.1.20}$$
   where we normalize $g_t = 0$.
   (b) fiscal policy, which governs the supply of government securities (collateral) in the economy,
   $$b_{t+1} = \bar{b}\, c_t, \tag{2.1.21}$$
   where $\bar{b}$ is a constant.
   (c) monetary policy.[13]

The set of general equilibrium conditions are provided in the appendix.

2.1.5 Interest rate spreads

Now, using the general equilibrium conditions, we are in a position to build the relation between various interest rates in the model. The chart in Figure 2.1 illustrates the link between various spreads and summarizes the following discussion.

[13]In case of perfectly flexible prices as in an RBC setup, the central bank adopts the neutral interest rate. In the New Keynesian framework with price stickiness, the interest policy rule will be specified.

"The shadow total yield" R_t^T is defined as the nominal risk-adjusted pecuniary return to a fictitious asset that offers no collateral services, therefore satisfies the ordinary Euler equation,

$$E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\right]\left(1+R_t^T\right)\equiv 1. \tag{2.1.22}$$

Portfolio balance requires that the sum of pecuniary and non-pecuniary return on any asset held by the household in equilibrium should equal R_t^T. Specifically, the deposit rate is lower than the shadow total yield by household valuation of monetary services. The spread represents our benchmark for quantifying the severity of banking distress, because in equilibrium it also reflects the cost of supplying monetary services by banks.

To analyze the cost components, it is useful to define the "shadow interbank rate" $R_t^{IB,T}$, that represents the total opportunity cost of loanable funds to banks[14] and thus satisfies

$$\frac{\Psi_t}{\lambda_t}+\frac{1+R_t^{IB,T}}{1+R_t^T}\equiv 1. \tag{2.1.23}$$

Therefore, the shadow interbank rate falls below the shadow total yield by the total marginal cost of extending loans to households Ψ_t/λ_t, as also seen in (2.1.10). Moreover, (2.1.10) implies that the deposit rate is lower than the shadow interbank rate by the total marginal cost of deposit servicing.

Each of cost components are in turn decomposed in terms of factors of loan production. The share of collateral could be thought of as rebated amount to the borrower. The lending bank accordingly charges the loan rate that accounts for the marginal cost of monitoring.[15] Therefore, the realized loan rate for households R_t^L and interbank rate R_t^{IB} satisfy,

$$R_t^T - R_t^L = \alpha\left(R_t^T - R_t^{IB,T}\right) \tag{2.1.24}$$

$$R_t^{IB,T} - R_t^{IB} = \frac{\tilde{\alpha}}{\ell}\left(R_t^{IB,T} - R_t^D\right). \tag{2.1.25}$$

The no arbitrage condition for government securities holding between households and banks determines the government bond rate in equilibrium. The government bond rate falls below the shadow total yield by the collateral services yield to the household. It should also fall below the shadow interbank rate by the collateral services yield to banks. The latter, in effect, captures the shadow TED spread in the model.

[14] Unlike deposits, loanable funds do not require servicing.

[15] Remember that perfect competition implies zero profit for banks.

2.1.6 The market for collateral services

I characterize equilibrium in the market for collateral services with the aim of identifying factors that influence the TED spread. Figure 3.1 displays model-implied demand and supply curves in this market, which is plotted from the banking point of view. The demand curve represents bank valuation of collateral services provided by government securities on the bank balance sheet per dollar of deposits. Collateral services yield displays diminishing returns with respect to collateral holdings by banks. The supply curve represents the total supply of government securities to banks net of household absorption of collateral and reflects the opportunity cost of holding government bonds by banks.

Banking demand for collateral services shifts up when the productivity of interbank loan technology goes down or the transaction demand per dollar of deposits increases. From a static perspective, these are reflected by a decline in $\tilde{F}$ and an increase in ℓ. Supply of collateral services to banks shifts up when loans to households become less productive, thereby elevating the opportunity cost of supplying collateral to banks or when the total supply of collateral drops. These are captured by declines in F and $\bar{b}$.

Now, I will examine the effect of these factors on our benchmark for the severity of banking distress, i.e. $R_t^T - R_t^D$. This is facilitated by looking at the two components of bank cost, which are expressed in terms of factor costs according to,

$$R_t^{IB,T} - R_t^D = \frac{\ell}{\tilde{F}} \left(\frac{R_t^{IB,T} - R_t^B}{\tilde{\alpha}} \right)^{\tilde{\alpha}} \left(\frac{w_t / A_t^{\tilde{m}}}{1 - \tilde{\alpha}} \right)^{1-\tilde{\alpha}} \tag{2.1.26}$$

$$R_t^T - R_t^{IB,T} = \frac{1}{F} \left(\frac{R_t^T - R_t^B}{\alpha} \right)^{\alpha} \left(\frac{w_t / A_t^{m}}{1 - \alpha} \right)^{1-\alpha}. \tag{2.1.27}$$

Therefore, factors that elevate the equilibrium TED spread also raise the costliness of banking. However, the relationship between the TED and $R^T - R^D$ is not monotonic and differs with respect to various sources of costliness.

2.2 Structural changes in the banking sector

Now, I turn to apply the analytical framework developed in the last section to study the underlying sources of banking distress in the U.S. from 1960 to 2006. In this section, I consider assessing structural changes in the banking sector in light of secular movements of the TED spread and other observables via the deterministic balanced-growth version of the model. I will consider short-run analysis in the next section.

The first step in this regard is to show that a plausible calibration exists that fits average values of relevant observables over the sample period. Next, to highlight the role of collateral, I will consider the exclusive effects of changes in the supply of government securities relative to GDP in explaining trend movements in the TED spread and other banking observables. Then, I back out the model-implied values of banking parameters that account for secular movements in these banking observations not explained by the collateral supply effect.

2.2.1 Calibration

There are fourteen parameters that need to specified. Six of these appear in New Keynesian models without money and banking. For these, I use values commonly found in the literature. The discount factor is set to $\beta = 0.99$ and the labor augmenting technology grows at an annual rate of 2 per cent corresponding to $\gamma = 0.005$ per quarter. This growth rate is common between the production sector and the banking sector to guarantee existence of a balanced growth equilibrium. Accordingly, the real annual value of the shadow total yield is 6 per cent at the steady state. The utility weight of consumption is ϕ is 0.4 and leisure 0.6 to yield 1/3 of total hours for employment in production and banking. In the goods production, it is assumed that the share of capital is $\eta = 0.36$ and the elasticity of goods sales is $\theta = 11$ to yield a markup of 1.1. Moreover, capital is assumed to depreciate at annual rate of 10 percent implying $\delta = 0.025$.

Table 2.1: Parameter values under the baseline calibration

ϕ	0.4	β	0.99	V	0.44	α	0.60	$\tilde{\alpha}$	0.08
η	0.36	δ	0.025	$\bar{b}$	0.90	F	22	$\tilde{F}$	144
γ	0.005	θ	11			k	0.0255	ℓ	0.81

Two of the money and banking parameters are directly observable. I use the quarterly data for all depository institutions. The velocity of bank deposit circulation per quarterly GDP is on average $V = 0.44$ from 1960 to 2006. The government securities collateral relative to quarterly GDP is set to $\bar{b} = 0.90$, which is the average of sums of Treasury securities and securities issued by Government Sponsored Enterprises (GSEs) relative to quarterly GDP over the sample. This includes holdings of households, corporations and banking holding and excludes foreign and government holding as well as insurance holding. This choice takes into account that government holding provides collateral services to their holder in the model. The data come from the Flow of Funds account.

There are six banking parameters to be calibrated. These are jointly calibrated to match averages of six observations in banking over the sample period as following. First, equilibrium in the market for collateral services is characterized by a TED spread of 115 basis points and government securities relative to deposits of 18.7 percent. Second, the real three-month T-Bill rate is on average 1.3 percent implying the collateral services yield of government securities of 4.7 percent. Next, the observable external finance premium, which represents the marginal cost of extending loans to households in the model is 1.9 percent in the sample, roughly the same as the value used in the literature. Moreover, the real deposit rate is -0.7 percent in the sample implying the total transaction cost of 6.7 percent.[16] Finally, the share of employment in the banking sector relative to total employment is 1.6 percent based on data obtained for banking employment from FDIC website and total employment from the Bureau of Labor Statistics.

2.2.2 Exclusive effects of collateral scarcity

Figures 2.3 to 2.6 illustrate observations of banking variables in the model. The historical data for the TED spread (Figure 2.3) reveals that movements of TED could be decomposed into a trend component and short-term component. Moreover, movements in the TED spread exhibit a generally inverse relationship with the bank holdings of government securities per dollar of deposits (Figure 2.4), which in turn co-moves with the supply of government securities relative to GDP (Figure 2.5). Motivated by these observations, I use the benchmark calibration to investigate the model-implied effect of observed changes in government securities (collateral) supply on the three observed variables of banking.

Figure 2.7 demonstrates that the exclusive effect of collateral scarcity accounts for a substantial part of the secular movements in banking observables, especially the TED spread and collateral holdings of banks. The model attributes elevated level of the TED spread in the earlier part of the sample (prior to 1990) to the scarcity of collateral and alternatively its low level in the later part of the sample to abundance of collateral. Similarly, the general increase in bank holdings of government securities over the sample period is explained by larger availability of collateral. These findings show that for any plausible interpretation of the TED spread for banking, it is essential to account for collateral supply effects (government securities relative to GDP).

2.2.3 Structural changes in banking

Now, I allow for changes in the three banking parameters F, $\tilde{\mathsf{F}}$ and ℓ, to fit secular movements in the banking observables, which are not explained by changes in collat-

[16] Interest rates and spreads are reported annually according to the convention. Note also that the loan rate and the deposit rate are calculations of author from the balance sheet data of all commercial banks in the U.S. obtained from the FDIC website. The deposit rate in particular is probably underestimated because of the prevalence of Regulation Q in the first part of the sample that prohibited banks from paying interest on deposits.

eral supply.

I first restrict attention to the earlier part of the sample during which collateral supply is relatively scarce. According to Figure 2.7 shows the scarcity of collateral supply should result in a higher TED spread with smaller bank holding of government securities on their balance sheet. However, observations indicate that there was not as much scarcity of collateral supply to banks, which resulted in higher bank holdings of collateral and less valuation of collateral services at the margin. There is yet another channel for the supply of government securities to banks, which works through less absorption of collateral by households. According to the framework of the market for collateral services (Figure 3.1), this could happen when bank productivity in issuing loans to households is higher relative to the benchmark calibration. Simulations confirm this explanation.

Next, I consider the later part of the sample that corresponds to general abundance of collateral. The diminishing returns to collateral holding by banks implies that the TED spread is insensitive to shifts in the supply curve. The exclusive effect of collateral in this period calls for higher holdings of collateral by banks and lower costliness of banking relative to observations. Among the sources of costliness of banking it is plausible to think that this outcome is reflective of lower bank productivity of extending loans to households, which shifts the supply of collateral curve and raise the cost of creating deposits.

Moreover, we observe underestimation of the loan–deposit rate spread and overestimation of bank holdings of collateral in the later part of the sample. This is a period with abundance of government securities collateral and due to diminishing returns, the In the framework of the market for collateral services, the abundance of government securities in this period has pushed the collateral supply curve to the region in with low sensitivity of TED spread. This explanation is consistent with the simulation findings.

There are other interesting dimensions of structural changes in banking that the model predicts. For instance, the productivity of interbank loans drops since late 1970s till early 1980s. This is the period in which the second oil crisis occurs in 1979 causing the "Great Panic" in the economy, and it is followed by the financial crises of 1978, 1979 and 1980.[17] Moreover, the Volker fed tightened money supply to fight against inflation. The model's prediction suggests that these ongoing events had a structural effect on bank productivity of issuing interbank credit, while other conditions did not cause this kind of lasting effect.

Furthermore, there is a generally declining trend in parameter ℓ, which implies lower demand for transaction services for the purposes of trading assets. One expla-

[17] Business week magazine posted a title "Death of Equities" in August of 1979 claiming that most of people's investment had shifted from stocks to money market instruments.

nation for this trend could be the emergence of the money market instruments over this period that offered higher interest rates relative to bank deposits and attracted away the demand for monetary services for asset trading purposes from banks.

2.2.4 Comparative Statics

At this stage, it is possible to use the comparative statics for banking parameters ($\bar{b}$, F, ℓ and $\tilde{F}$) to address the paper's main question from a long-term perspective. Table 2.2 reports the results for the shift in the parameter values in their possible range of changes.

Various dimensions of costliness of banking affect the banking and real sector differently. For example, compare the factors that shift the supply curve in the market for collateral services, namely $\bar{b}$ and F. Shift in the collateral supply affects the TED spread more severely, but it has a milder effect on aggregate consumption and costliness of banking services. However, a shift in the productivity of monitoring households has a smaller effect on the TED spread, yet it has a much deeper effect on the aggregate consumption and costliness of banking.[18]

To explain why this happens, suppose the economy is initially at the steady state equilibrium. Now, consider two new equilibria, one with a permanent drop in the suply of government securities relative to GDP, $\bar{b}$, and another with a permanent drop in the productivity of loans to households, F, such as to produce 100 basis point elevation in the TED spread in both cases.[19] In each case, the marginal cost of servicing deposits increases equally, which is governed by the banking demand for collateral services. However, the marginal cost of extending loans to households rises substantially higher when the loan technology becomes less productive compared with the general scarcity of collateral. In effect, the sensitivity of marginal cost with respect to the collateral services yield goes up when the loan productivity drops (see equation (3.3.15)). Moreover, households value collateral services higher at the margin because of the decrease in the loan productivity, which reinforces the previous effect. Altogether, the difference in the marginal cost of monetary services amounts to 440 basis points.

In this respect, the trend movements in the TED spread does not consistently indicate severity of costliness of banking, even though it reflects the direction of change correctly. This is confirmed by shifts in the sign of correlation between the TED spread and the loan–deposit rate spread (observed measure of costliness of banking) over the sample. The correlation values are 0.56, −0.44 and 0.52 from 1960 to 1983, 1983 to 1995

[18]Similarly, the factors affecting the banking demand for collateral services namely ℓ and $\tilde{F}$ impact the TED spread and costliness of banking services (hence aggregate consumption) differently.

[19]That is roughly 20% drop in collateral supply and 35% drop in the productivity of loans to households.

and 1995 to 2006 respectively.

Table 2.2: Comparative statics.

	TED	B^b/D	$R^L - R^D$	$\bar{b}$	F	ℓ	$\tilde{F}$	c	n	$R^T - R^D$
benchmark	1.15%	0.19	4.79%	0.90	22	0.81	144	0.8085	0.3282	6.73%
Low $\bar{b}$	3.42%	0.08	5.59%	**0.58**	22	0.81	144	0.8044	0.3261	8.33%
High $\bar{b}$	0.38%	0.37	4.33%	**1.24**	22	0.81	144	0.8112	0.3295	5.90%
Low F	2.46%	0.10	7.66%	0.90	**13**	0.81	144	0.7888	0.3192	13.65%
High F	0.79%	0.24	4.12%	0.90	**30**	0.81	144	0.8131	0.3303	5.18%
High ℓ	1.30%	0.20	5.47%	0.90	22	**0.95**	144	0.8054	0.3269	7.47%
Low ℓ	0.77%	0.15	3.25%	0.90	22	**0.49**	144	0.8158	0.3312	5.01%
Low $\tilde{F}$	1.59%	0.23	8.06%	0.90	22	0.81	**79**	0.7936	0.322	10.29%
High $\tilde{F}$	1.07%	0.18	4.29%	0.90	22	0.81	**165**	0.8108	0.3292	6.18%

2.3 Episodes of banking distress

Now we can turn our attention to studying episodes of banking distress identified by sharp spikes in the TED spread (the short-term component). Specifically, I use the log-linearized version of the model around the benchmark calibration but with banking parameter values that account for the structural changes explored in the previous section. Based on observations of banking variables, I first identify the sources of banking distress and quantify the size of underlying shocks. The next step is to evaluate the response of the model variables to these shocks with the aim of comparing the intensity of banking distress for various elevations in the TED spread across different episodes. Further, I assess the transmission of banking distress to aggregate consumption and employment.

I consider seven episodes of distress in the history of banking from 1960 to 2006 that correspond to sharply elevated TED spreads. These instance coincide with certain events relevant to banking and I choose one title to label each as following: a) the commercial paper crisis of 1969, b) the banking crisis of 1974, c) the Volker disinflation era in 1981, d) The stock market crash of 1987, e) the credit crunch of 1990, f) the Russian debt crisis of 1998, and g) the dot-com bubble of 1999.[20]

[20] To provide a sense of the nature of banking distress, consider the events that occurred around 1974, during which the TED spread reached its historical high record of 500 basis points: a) the economic recession followed by the energy crisis in 1973, b) a large shock to commercial paper market due to financial problems of W.T. Grants company, c) failure of large international banks in particular the German Bankhaus Herstatt that was thought to "threaten the international financial order" (Schwartz 1987) and created a crisis in the payments system, e) failure of large national banks most notably the Franklin National Bank and the United States National Bank of San Diego. (Markham 2002)

2.3.1 Short-term dynamic responses

To complete characterization of the full log-linearized New Keynesian model, we need to specify the interest rate rule of the central bank and the price movement relationship. To restrict attention to real effect and replicate core RBC model, I consider a perfectly price stabilizing policy specified as

$$R_t^{IB} = \mu_1 \cdot \Delta p_t, \tag{2.3.1}$$

where $\mu_1 = 50$. Moreover, in keeping with the literature I assume the dynamics of prices follows a Calvo (1983) style mechanism according to,

$$\Delta p_t = \beta \cdot E_t \Delta p_{t+1} + \kappa \cdot mc_t, \ \kappa > 0 \tag{2.3.2}$$

where Δp_t represents the inflation rate, $\kappa = 0.05$ consistent with values found in the new Keynesian literature and mc represents the real marginal cost of goods production (inverse of markup), given by $mc_t = \hat{w}_t + \hat{n}_t - \hat{c}_t$.

To identify the sources of shocks to banking that generate spikes in the TED spread, consider the following features common among all instances of banking distress:

1. The TED spread elevates substantially and quickly reverts back to its trend value in the next period.

2. The supply of government securities is relatively invariant during the episode.

3. Bank holding of government securities per dollar of deposits does not vary significantly.

4. There is generally great uncertainty and information asymmetry between lenders and borrowers in all credit markets (interbank market and loans to households).

In the framework of the market for collateral services, the above situation cannot arise as a result of only one shock but shocks that shift the supply and demand curves equiproportionately upward. Therefore, it is plausible to think that it is an equiproportionate shock to the productivity of monitoring households and interbank monitoring, i.e. A_t^m and $A^{\tilde{m}_t}$ with small persistence that describes banking distress.

An important message of the comparative statics in the previous section was that the model's response is highly non-linear with respect to shocks to banking. Note however that with the above interpretation of banking distress, as a result of an equal upward shift in the supply and demand curves, there is a small change in the slops of curves in the new equilibrium. Hence, the linear model is a good approximation even with large size of shocks. Non-linearity would matter if only one curve shifts thereby leading to a different slope than the initial equilibrium point on both curves. See Figure 2.9 for an illustration.

Now, I use the TED spread deviations from their trend to quantify the sizes of shocks to the general productivity of banking at each episode. Table 2.3 displays the results of simulations for various episodes of banking distress.[21]

Simulations highlight that banking distress shows up as deep shocks to the productivity of monitoring, which in turn has a substantial real effect on aggregate consumption and employment in the economy. The transmission mechanism of banking stress to aggregate consumption works through demand-side and supply-side effects. The demand-side effect of banking stress works through raising the transaction tax on consumption. A large stress in banking causes banks to utilize higher monitoring per dollar of loan, which has a mild positive effect on wage because banking sector takes a small fraction of total employment. As a result, the cost of creation and servicing deposits go up leading to higher transaction tax, which in turn decreases the consumption demand. There is a supply effect because higher employment in banking results in a contraction of residual supply of labor to the production sector.

The dynamic effect of transaction tax is reflected in the total rate R^T. Normally, in models without transaction cost, an initial reduction in consumption followed by an expected rise gives rise to an elevation in the total interest rate. However, with a temporary high transaction cost acts like a temporary tax on consumption and encourages consumers to postpone consumption to future periods. In our model's calibration, the transaction tax effect turns out to be stronger than the expected increase in consumption. This explains why the total yield drops even though consumption is expected to rise.

The above discussion is illustrated by the log-linearized Euler equation,

$$\hat{R}_t^T - E_t \Delta p_{t+1} = (E_t \hat{c}_{t+1} - \hat{c}_t) + \underbrace{\frac{1}{V}\left(E_t\left(\hat{R}_{t+1}^T - \hat{R}_{t+1}^D\right) - \left(\hat{R}_t^T - \hat{R}_t^D\right)\right)}_{\text{expected change in ``banking services tax''}}. \tag{2.3.3}$$

With transaction tax, the second expression above appears in the Euler equation. As soon as banking is shocked, the first expression goes up while the second expression shrinks. In our model, the second effect is larger than the first effect which explains the dynamic response as reflected by reduced total yield.

For the purposes of illustration, the effect of a permanent transaction tax is replicated by a high persistence parameter of shocks. Results are exhibited in Figure 2.10. The transaction tax effect is now absent because its effect is expected to persist and thus

[21] As an illustration of the pattern of the economy's response to banking distress, a typical case is displayed in Figure 2.10 that uses the benchmark calibration and size of shock is set to generate 100 basis-point elevation in the TED spread.

Table 2.3: Impulse responses of banking and real variables at the period of elevated TED spread for various episodes with extreme stress in banking

	TED	**ΔTED**	$\bar{b}$	F	$\tilde{F}$	ℓ	$\mathbf{R}^{T}$	$\mathbf{R}^{T}-\mathbf{R}^{D}$	**c**	**n**	**shock**
Com. Paper crisis, 1969	400	200	0.74	22.8	144	0.88	-185	787	-3.7	-4.4	107%
Banking Crisis, 1974	500	300	0.57	28.5	130	0.65	-188	806	-3.8	-4.5	140%
Volker Disinflation, 1981	335	120	0.58	30	80	0.60	-80	371	-1.8	-2.1	50%
Stock Market Crash, 1987	205	100	0.94	20	144	0.80	-160	641	-3.0	-3.5	90%
Credit Crunch, 1990	110	35	1.02	16	70	0.36	-74	285	-1.3	-1.5	33%
Russian Debt crisis, 1998	100	40	1.17	15	144	0.65	-158	568	-2.6	-3.0	68%
Dot-com Bubble, 1999	105	50	1.19	14	164	0.70	-228	812	-3.7	-4.3	90%

Note: Total elevations in the TED spread (labeled 'TED') and temporary deviations (labeled 'ΔTED') are reported in the second and third columns respectively. All interest rates and spreads are reported in basis points annual terms. Real variables are fractional deviation from their steady state values. All values correspond to the impulse responses at the date in which the banking distress impacts the economy.

impacts permanent consumption at a lower rate. The total rate changes insignificantly consistent with the above intuition.

Let's now focus attention to the consistency of TED in capturing the intensity of banking stress. Simulations show that the TED spread always spikes during an extreme banking stress. However, TED elevations are not consistent in capturing the intensity of stress. Consider the commercial paper crisis of 1969 and its succeeding banking crisis in 1974. TED spikes are different by 100 basis points, while there is almost same stress in terms of real effects and cost of banking. Moreover, in the Dot-Com bubble of late 1999 short-term component of TED widens by 50 basis points, whereas the stress is almost the same as previous events.

The disconnection between TED and transaction cost is clearly seen when comparing the 1981 Volker disinflation era with the 1987 stock market crash.

The inconsistency of the TED spread could be attributed to the collateral supply differences. Collateral is most scarce in 1974 and most abundant in 1999 among the rest of our list of stress episodes. This explanation reinforces the finding of the role of collateral supply on the long-term component regarding the role of collateral supply on TED movements.

Results exhibit a disconnection between TED spikes and transaction tax. To see this, consider responses of Volker disinflation in 1981 and the stock market crash of 1987. Short-term elevation in TED is about 100 basis point in both cases, whereas the net cost of transaction services is almost twice in the latter case. The disconnection is attributed to structural differences in banking and in particular the productivity of issuing loans to households, which is much lower in the latter episode. However, the increase in the supply of collateral masks this difference by implying a similar elevation in TED.

Overall, the discussion of this section implies that non-linearity of banking is an important feature that could imply totally different quantitative implications. In particular, the model suggests that the TED spread is an inconsistent indicator of the intensity of stress and an appropriate analysis requires taking account of the supply of collateral as well as structural parameters of the banking sector.

2.4 Concluding remarks

I conclude by summarizing the main scope of the paper, its main findings and possible future directions to extend the model. My objective in this paper was to question conventional wisdom that the short-term common maturity interbank Treasury-Bill ("TED") spread is a consistent indicator of stress in the banking sector where banking stress occurs to raise the cost of providing transaction-facilitating deposits by banks (an implicit transaction tax on consumption). I argue that a general equilibrium approach to banking and rate spreads sheds light to aspects of the link between TED and costliness of banking that reveals at time TED could be an inconsistent and misleading indicator. My analytical framework incorporates an otherwise standard new Keynesian model with a perfectly competitive banking sector in which banks monitor households to extend loans and borrow interbank credit to facilitate payments. Government securities play an important role by defraying the cost of monitoring and thereby providing collateral services to borrowers. Therefore, the TED spread reflects valuation of collateral services by banks and it is determined by equilibrium in the market for collateral services.

My quantitative analysis has both long-term and short-term dimensions. First, I assess structural changes in banking over the sample period from 1960 to 2006. Comparative statics reveals that a shift in the supply of collateral is associated with a substantial change in TED but mild differences in real variables and the transaction tax. However, a shift in productivity of bank monitoring results in less intensive change in TED yet significant real effects. This insight helps us understand why the TED spread was particularly low during 1990s whereas the cost of banking services got quite high. Next, I study the local dynamics of economy during episodes of extreme stress in banking as indicated by TED spikes while taking account of structural changes in banking. I find that there is a stark difference between the intensity of stress and elevation in TED that arises because of underlying differences in collateral supply and bank monitoring productivity. Ultimately, I complete my argument by showing that the central bank who regards TED as indicator of banking stress may cause macroeconomic instability. Instead, I propose the central bank should respond to loan-deposit rate spread to effectively perform in cases of banking stress.

The model could be potentially extended in various dimensions to address interesting problems. Here I discuss three of them. First, I recognize the substantial real implications of banking stress that arises from a large implied transaction tax. One way to make the model more realistic is to consider a short-term monitoring specific supply of labor to take account of the fact that monitoring effort supply is segmented from the rest of the labor market in the short-run. In that case, shocks to productivity of monitoring is expected to affect the monitoring-specific wage, without raising the demand for monitoring as severely as in the original model. This modification would alleviate the supply-side effect, but the demand-side effect would be mixed and needs further investigation in a calibrated setup. Next, the model abstracts from differences in the transaction services provided by various types of deposits. It also does not explicitly model transaction services offered by the money market. These modifications can alleviate the transaction tax effect. Finally, bank demand for interest-bearing reserves is absent from the model. To study monetary policy after financial crisis, the model first needs to be elaborated in that direction.

Appendices

Appendix B

B.1 Dynamic Equations

$$V\left(\frac{\phi}{c_t\lambda_t}-1\right)=\frac{R_t^T-R_t^D}{1+R_t^T} \tag{B.1.1}$$

$$E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\right](1+R_t^T)=1 \tag{B.1.2}$$

$$\frac{1-\phi}{1-n_t-m_t-\tilde{m}_t}=w_t\lambda_t \tag{B.1.3}$$

$$1=k\Omega_t^h\cdot\mathtt{EFP}_t+E_t\left(\frac{1+r_{t,t+1}^K}{1+r_t^T}\right) \tag{B.1.4}$$

$$\frac{R_t^T-R_t^B}{1+R_t^T}=\Omega_t^h\cdot\mathtt{EFP}_t \tag{B.1.5}$$

$$\frac{R_t^{IB,T}-R_t^B}{1+R_t^T}=\Omega_t^b\cdot\mathtt{MC}_t^{IB} \tag{B.1.6}$$

$$w_tm_t=\mathtt{EFP}_t(1-\alpha)L_t^h/P_t \tag{B.1.7}$$

$$w_t\tilde{m}_t=\mathtt{MC}_t^{IB}(1-\tilde{\alpha})L_t^{IB}/P_t \tag{B.1.8}$$

$$K^\eta(A_t^n n_t)^{1-\eta}=c_t+\delta Kq_t \tag{B.1.9}$$

$$b_{t+1}^h+b_{t+1}^b=A_t^{\bar{b}}\,\bar{b}\cdot c_t \tag{B.1.10}$$

$$VD_t/P_t=c_t \tag{B.1.11}$$

$$L_t^h/P_t+b_{t+1}^b=D_t/P_t \tag{B.1.12}$$

$$L_t^{IB}/P_t=A_t^\ell\ell\cdot D_t/P_t \tag{B.1.13}$$

$$L_t^{IB}/P_t=\tilde{F}\left(b_{t+1}^b\right)^{\tilde{\alpha}}(A_t^{\tilde{m}}\tilde{m}_t)^{1-\tilde{\alpha}} \tag{B.1.14}$$

$$L_t^h/P_t=F\left(b_{t+1}^h+kq_tK_{t+1}\right)^{\alpha}(A_t^m m_t)^{1-\alpha} \tag{B.1.15}$$

$$\frac{R_t^T-R_t^L}{1+R_t^T}=\alpha\cdot\mathtt{EFP}_t \tag{B.1.16}$$

$$\frac{R_t^{IB,T}-R_t^{IB}}{1+R_t^T}=\frac{\tilde{\alpha}}{A_t^\ell\ell}\cdot\mathtt{MC}_t^{IB}, \tag{B.1.17}$$

which solve for c_t, D_t/P_t, R_t^B, n_t, w_t, q_t, b_{t+1}^h, b_{t+1}^b, m_t, $\tilde{m}_t$, λ_t, R_t^T, R_t^L, $R_t^{IB,T}$, R_t^{IB} and R_t^D, given processes for evolution of shocks A_t^n, A_t^m, $A_t^{\tilde{m}}$, A_t^ℓ and $A_t^{\bar{b}}$. Also define,

$$\Omega_t^h \equiv \frac{\alpha\, L_t^h/P_t}{b_{t+1}^h + kq_t K} \qquad \Omega_t^b \equiv \frac{\tilde{\alpha}\, D_t/P_t}{b_{t+1}^b}$$

$$\mathtt{EFP}_t \equiv \frac{R_t^T - R_t^{IB,T}}{1+R_t^T} \qquad \mathtt{MC}_t^{IB} \equiv \frac{R_t^{IB,T} - R_t^D}{1+R_t^T}$$

$$1 + r_{t,t+1}^K \equiv (1-\delta)\frac{q_{t+1}}{q_t} + \frac{\eta \cdot mc_{t+1}}{q_t}\left(\frac{A_{t+1}^n n_{t+1}}{K}\right)^{1-\eta} \qquad mc_{t+1} \equiv \frac{w_t n_t}{(1-\eta)(c_t + \delta K q_t)}$$

B.2 Log-linearized Dynamic Equations

$$\frac{V\phi}{c\lambda}\left(-\hat{c}_t - \hat{\lambda}_t\right) = \frac{1+R^D}{1+R^T}\left(\hat{R}_t^T - \hat{R}_t^D\right) \tag{B.2.1}$$

$$\hat{R}_t^T = -E_t\hat{\lambda}_{t+1} + \hat{\lambda}_t + E_t\Delta p_{t+1} \tag{B.2.2}$$

$$\hat{\lambda}_t + \hat{w}_t = \frac{n}{1-n-m-\tilde{m}}\hat{n}_t + \frac{m}{1-n-m-\tilde{m}}\hat{m}_t + \frac{\tilde{m}}{1-n-m-\tilde{m}}\hat{\tilde{m}}_t \tag{B.2.3}$$

$$\hat{mc}_t = \hat{n}_t + \hat{w}_t - \hat{c}_t \tag{B.2.4}$$

$$0 = k\Omega^h \cdot \mathtt{EFP}\left(\hat{\mathtt{EFP}}_t + \hat{\Omega}_t^h\right) - \frac{1+r^K}{1+r^T}\left(\hat{r}_t^T - E_t\hat{r}_{t,t+1}^K\right) \tag{B.2.5}$$

$$\frac{\hat{R}_t^T - \hat{R}_t^B}{R^T - R^B} = \hat{\mathtt{EFP}}_t + \hat{\Omega}_t^h + \hat{R}_t^T \tag{B.2.6}$$

$$\frac{\hat{R}_t^{IB,T} - \hat{R}_t^B}{R^{IB,T} - R^B} = \hat{\mathtt{MC}}_t^b + \hat{\Omega}_t^b + \hat{R}_t^T \tag{B.2.7}$$

$$\hat{w}_t + \hat{m}_t = \hat{\mathtt{EFP}}_t + \hat{L}_t^h - \hat{P}_t \tag{B.2.8}$$

$$\hat{w}_t + \hat{\tilde{m}}_t = \hat{\mathtt{MC}}_t^b + a_t^\ell + \hat{D}_t - \hat{P}_t \tag{B.2.9}$$

$$\hat{c}_t = \left(1 + \frac{\delta K}{c}\right)(1-\eta)(\hat{n}_t + a_t^n) - \frac{\delta K}{c}\hat{q}_t \tag{B.2.10}$$

$$b^h \cdot \hat{b}_{t+1}^h + b^b \cdot \hat{b}_{t+1}^b = \bar{b}\left(a_t^{\bar{b}} + \hat{c}_t\right) \tag{B.2.11}$$

$$\hat{c}_t = \hat{D}_t - \hat{P}_t \tag{B.2.12}$$

$$L^h\left(\hat{L}_t^h - \hat{P}_t\right) + b^b\left(\hat{b}_{t+1}^b\right) = D\left(\hat{D}_t - \hat{P}_t\right) \tag{B.2.13}$$

$$\tilde{\alpha} \cdot \hat{b}_{t+1}^b + (1-\tilde{\alpha})\left(a_t^{\tilde{m}} + \hat{\tilde{m}}_t\right) = a_t^\ell + \hat{D}_t - \hat{P}_t \tag{B.2.14}$$

$$\hat{R}_t^T - \hat{R}_t^L = \alpha\left(\hat{R}_t^T - \hat{R}_t^{IB,T}\right) \tag{B.2.15}$$

$$\hat{R}_t^{IB,T} - \hat{R}_t^{IB} + \left(R^{IB,T} - R^{IB}\right)a_t^\ell = \frac{\tilde{\alpha}}{\ell}\left(\hat{R}_t^{IB,T} - \hat{R}_t^D\right) \tag{B.2.16}$$

$$\hat{L}_t^h - \hat{P}_t = \alpha\left(\frac{b^h}{b^h + kK} \cdot \hat{b}_{t+1}^h + \frac{kK}{b^h + kK} \cdot \hat{q}_t\right) + (1-\alpha)\left(a2_t + \hat{m}_t\right) \tag{B.2.17}$$

$$\Delta p_t = \beta E_t \Delta p_{t+1} + \kappa\, mc_t \tag{B.2.18}$$

$$\hat{R}_t^{IB} = (1+\mu_1)\Delta p_t + \mu_2 \cdot \hat{mc}_t, \tag{B.2.19}$$

which solve for c, w, q, λ, n, Δp, mc, D, L^h, b^b, b^h, m, $\tilde{m}$, R^T, R^L, $R^{IB,T}$, R^{IB}, R^B, R^D.

$$\hat{r}^K_{t,t+1} \equiv \frac{1-\delta}{1+r^K}\left(\hat{q}_{t+1}-\hat{q}_t\right) + \frac{\eta \cdot mc}{1+r^K}\left(\frac{n}{K}\right)^{1-\eta}\left(\hat{mc}_{t+1} + (1-\eta)(a1_{t+1} + n_{t+1}) - \hat{q}_t\right)$$

$$\hat{EFP}_t \equiv \frac{\hat{R}^T_t - \hat{R}^{IB,T}_t}{R^T - R^{IB,T}} - \hat{R}^T_t \qquad \hat{MC}^b_t \equiv \frac{\hat{R}^{IB,T}_t - \hat{R}^D_t}{R^{IB,T} - R^D} - \hat{R}^T_t$$

$$\hat{\Omega}^h_t \equiv \hat{L}^h_t - \hat{P}_t - \left(\frac{b^h}{b^h + kK} \cdot \hat{b}^h_{t+1} + \frac{kK}{b^h + kK} \cdot \hat{q}_t\right) \qquad \hat{\Omega}^b_t \equiv \hat{D}_t - \hat{P}_t - \hat{b}^b_{t+1}.$$

B.3 Log-linearization rules

As the model involves several interest rate spreads, a brief description of the rules that apply in such cases is worth mentioning. This explanation is also helpful in understanding how to interpret the impulse response function diagrams illustrated in the article.

To log-linearize a non-interest rate variable, the convention is to use the fractional deviation of the variable from its steady state value, denoted by a hat on that variable, $\hat{x}_t = \frac{x_t - x}{x}$. Now converted to a fraction, the unit of the original variable will not matter for the analysis.

In case of interest rates or returns that are already unit-less, their absolute changes from steady state will be considered, $(1 + r_t) = (1 + r)(1 + \hat{r}_t)$. Note that the definition of a return variable with hat is in effect absolute deviation from its steady state value. With rate spreads defined as $A_t = R^T_t - R^B_t$, we have $\hat{A}_t = \frac{1}{R^T - R^B}\left(\hat{R}^T_t - \hat{R}^B_t\right)$.

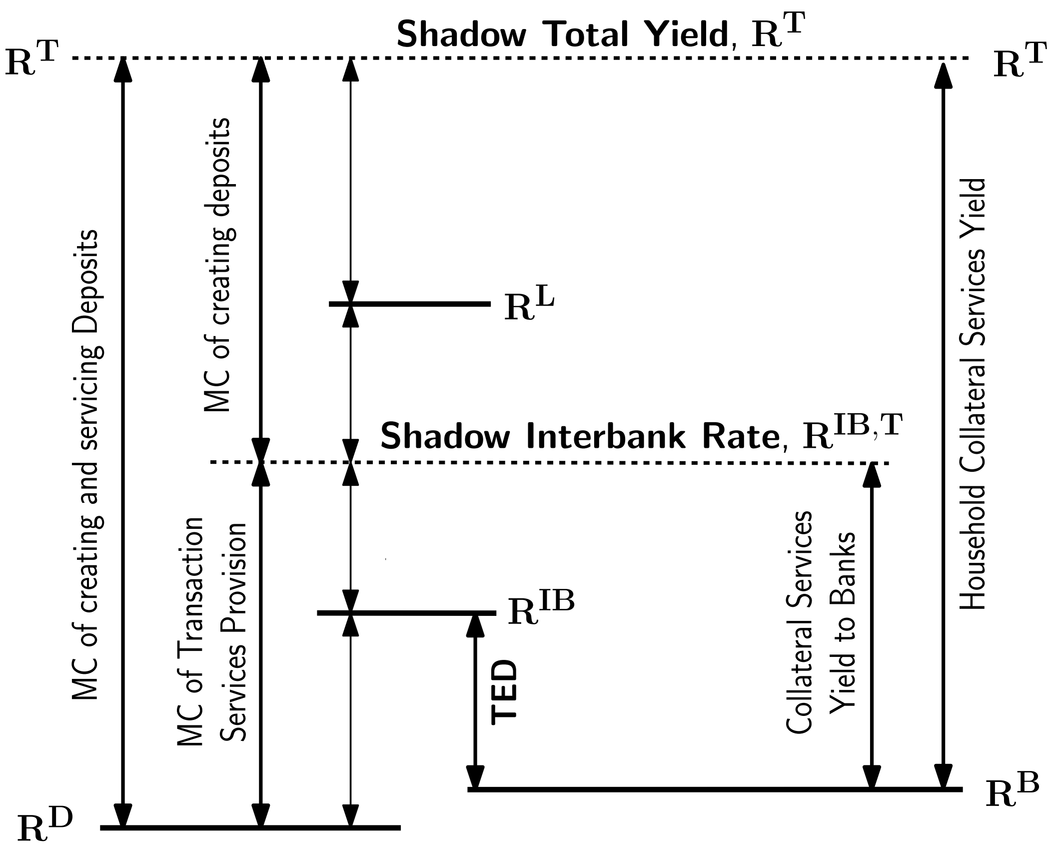


Figure 2.1: Interest rate spreads.

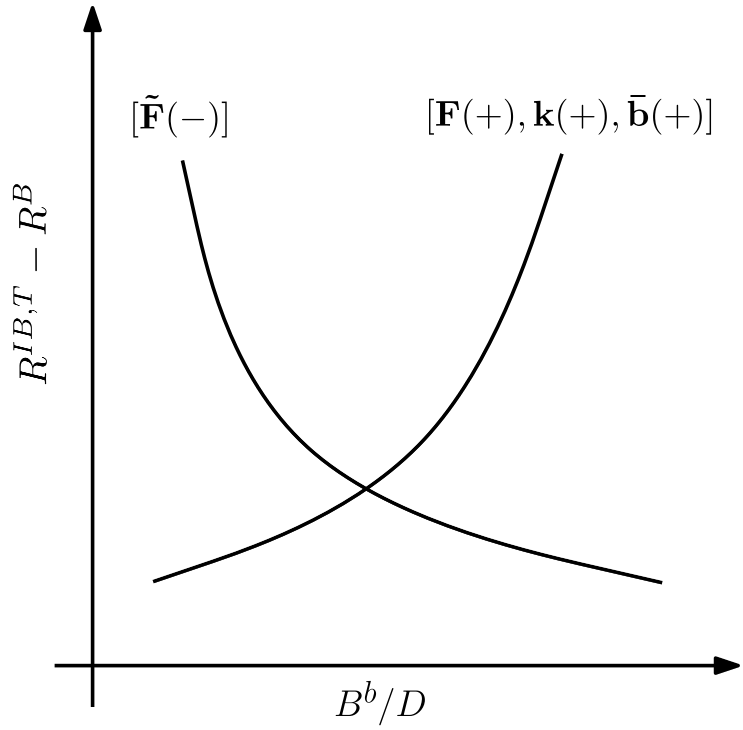


Figure 2.2: The market for collateral services.

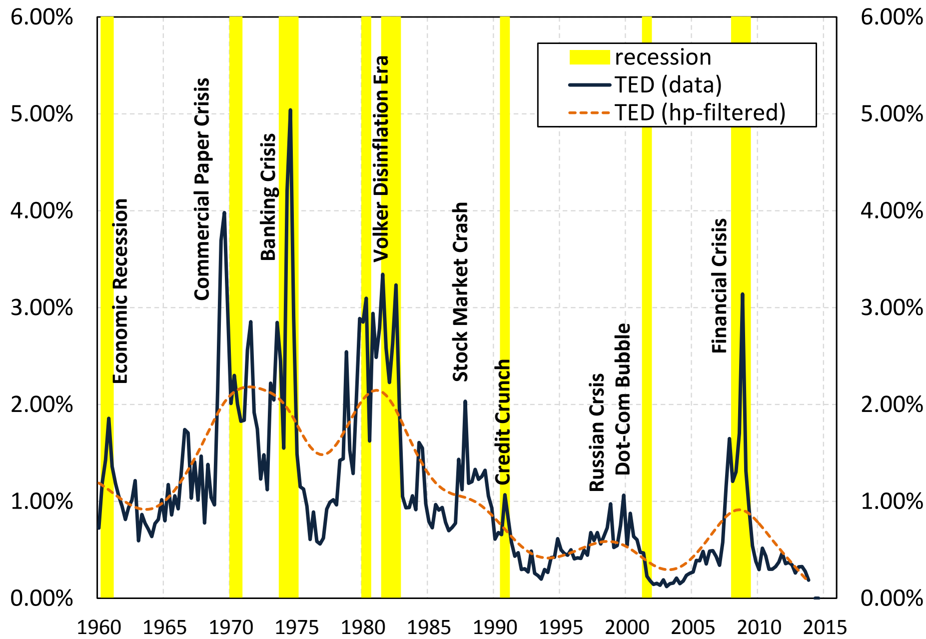


Figure 2.3: The TED spread

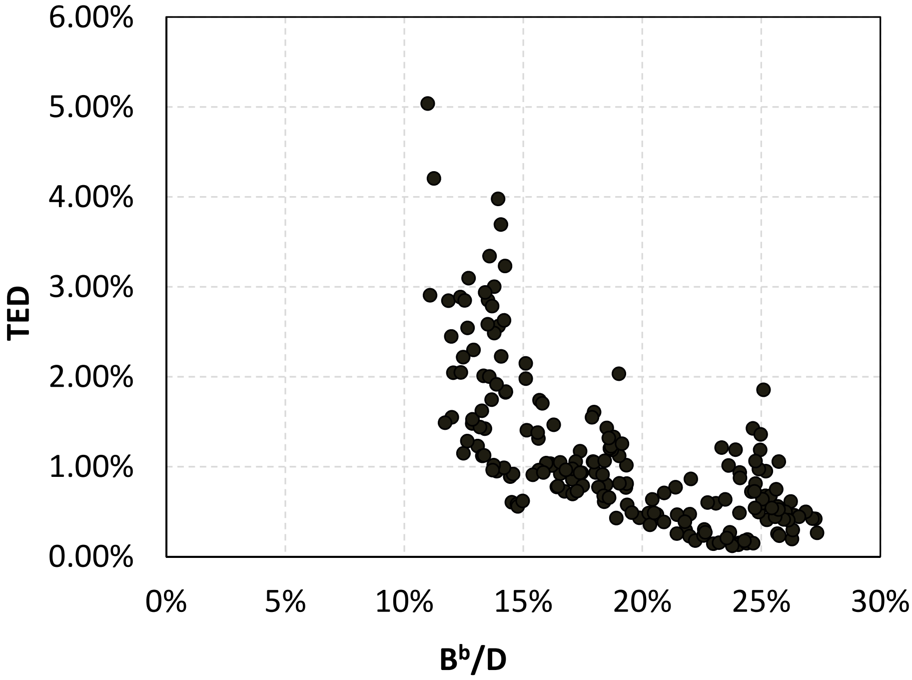


Figure 2.4: TED vs. B^b/D (1960–2006)

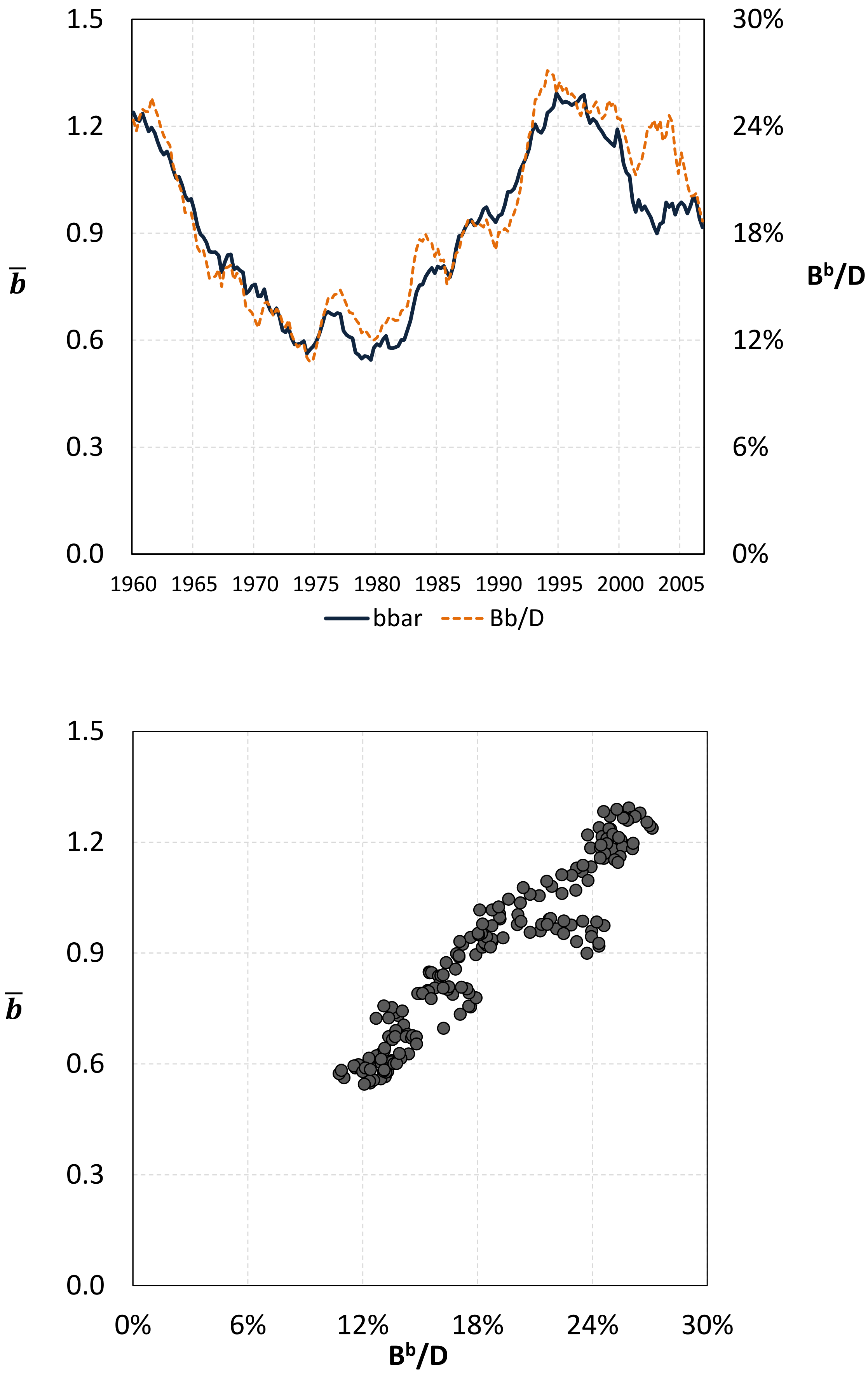


Figure 2.5: Collateral supply vs. B^b/D

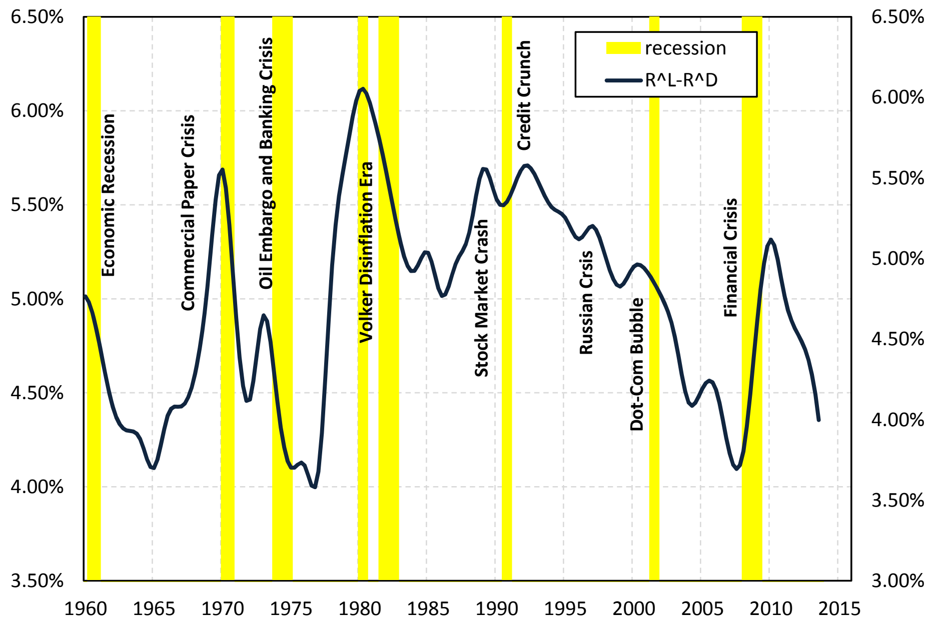


Figure 2.6: The Loan–Deposit rate spread

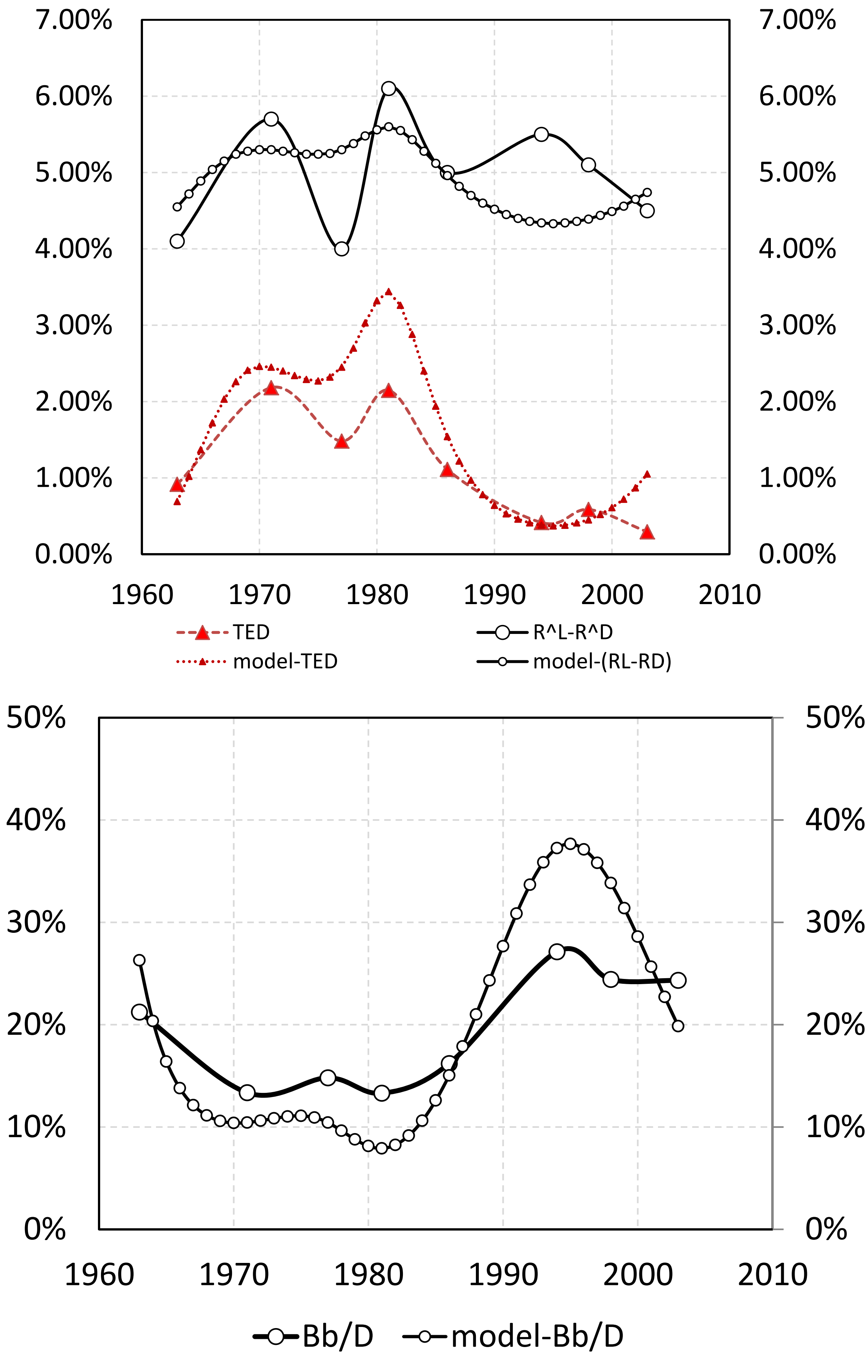


Figure 2.7: Exclusive effects of the supply of government securities.

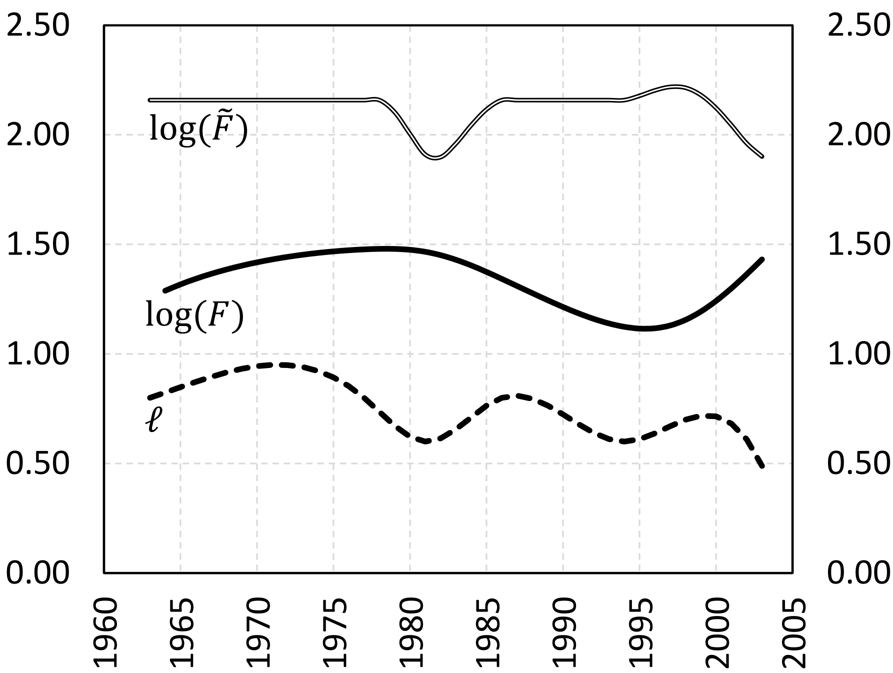


Figure 2.8: Structural changes in the banking parameters

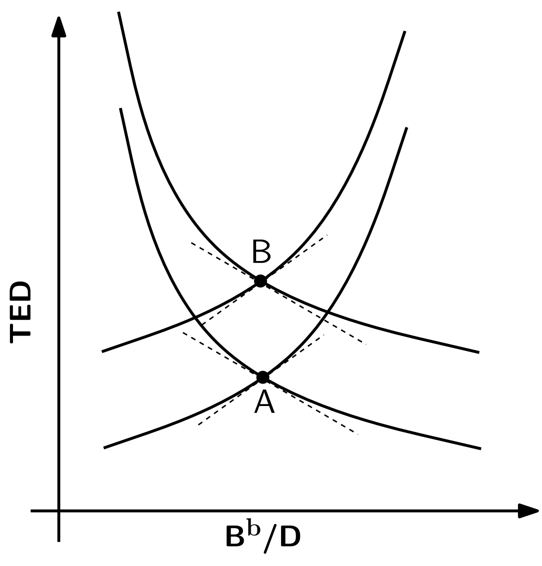


Figure 2.9: Linear approximation of banking distress.

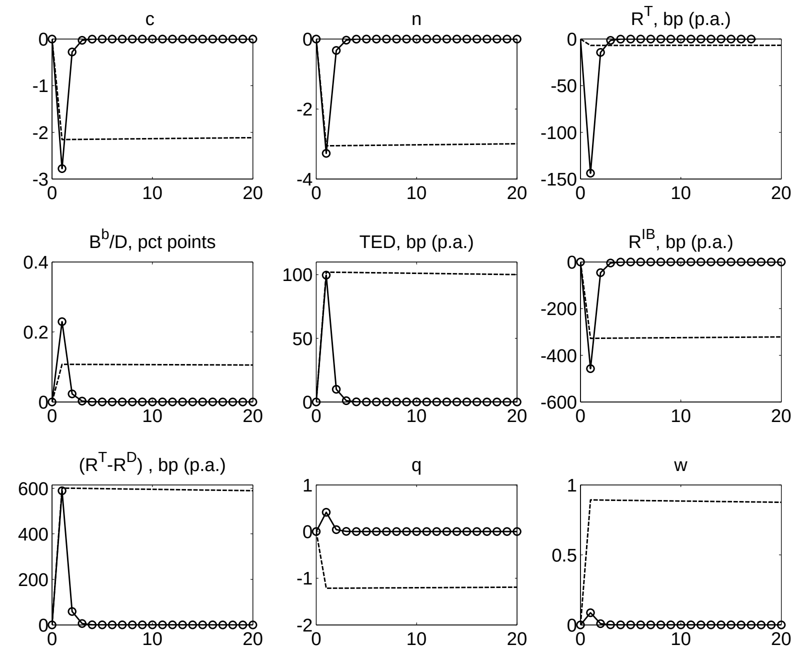


Figure 2.10: Impulse Responses to Banks' Monitoring Productivity Shock A_t^m and $A_t^{\tilde{m}}$

Note: Persistence of shocks is $\rho = 0.1$ (circle-line) and $\rho = 0.999$ (dashed line) to generate 100 basis-point elevation in the TED spread with the benchmark calibration. The dashed line is the counterfactual permanent shock to banking. All interest rates and spreads are reported in basis points and annually.

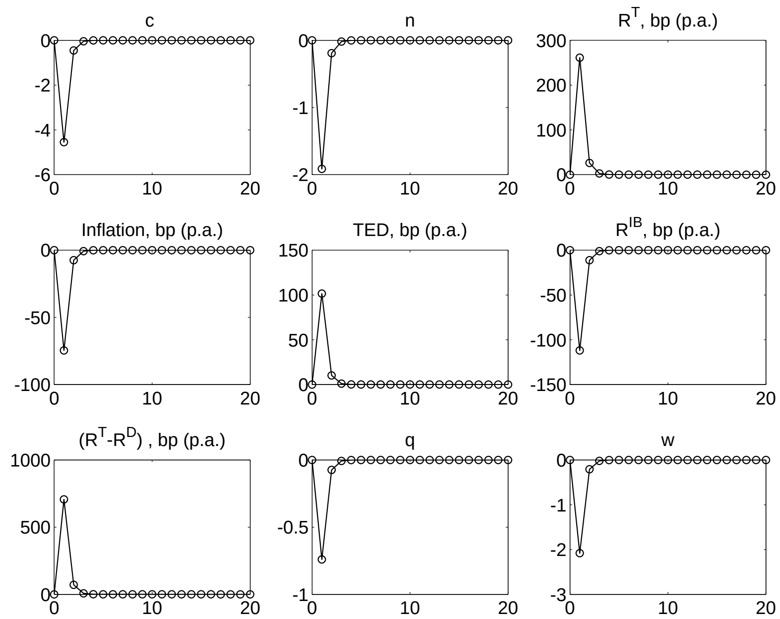


Figure 2.11: Impulse Responses to Banking Stress under Taylor Rule

Note: The shock generates 100 basis point elevation in TED with a standard Taylor rule. All interest rates and spreads are reported in basis points and annually.

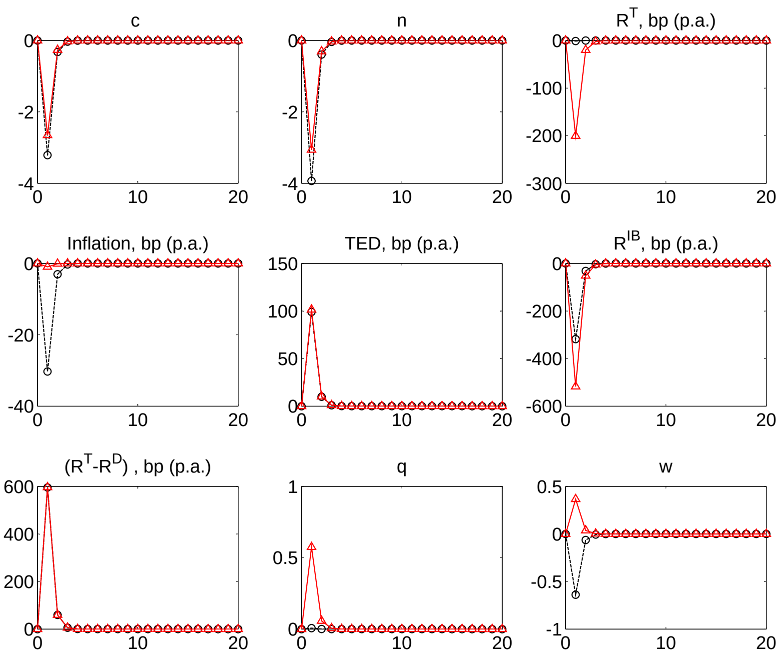


Figure 2.12: Impulse Responses to Banking Stress under Modified Taylor Rule
Note: The shock generates 100 basis point elevation in TED with a modified Taylor rule that responds to elevations in the TED spread. The red triangle solid line represents the modified rule and the circle dashed line represents a standard Taylor rule. All interest rates and spreads are reported in basis points and annually.

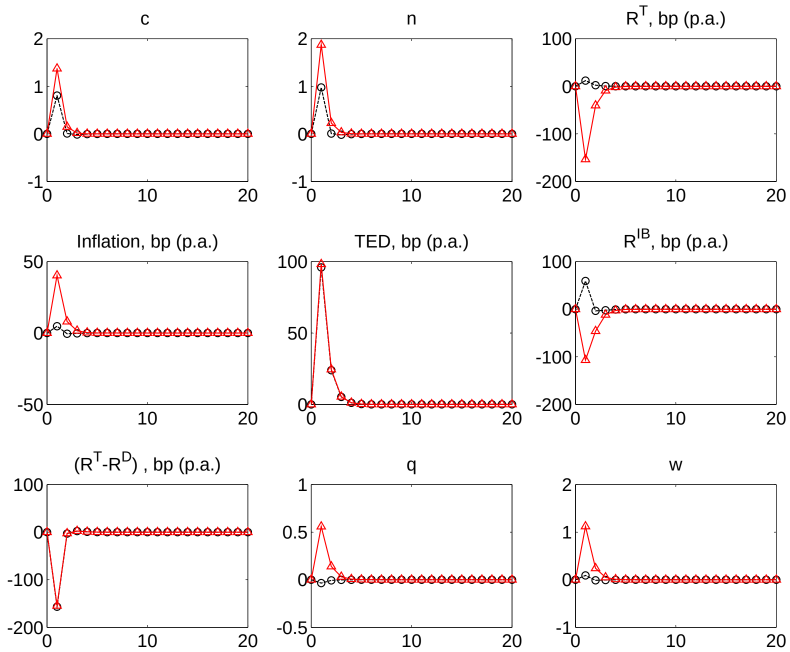


Figure 2.13: Impulse Responses to Counterfactual Banking Stress under Modified Taylor Rule
Note: The shock represents negative shock to $a_t^{\bar{b}}$ and positive shock to a_t^m and $a_t^{\tilde{m}}$ that generates 100 basis point elevation in TED with a modified Taylor rule that responds to elevations in the TED spread. The red triangle solid line represents the modified rule and the circle dashed line represents a standard Taylor rule. All interest rates and spreads are reported in basis points and annually.

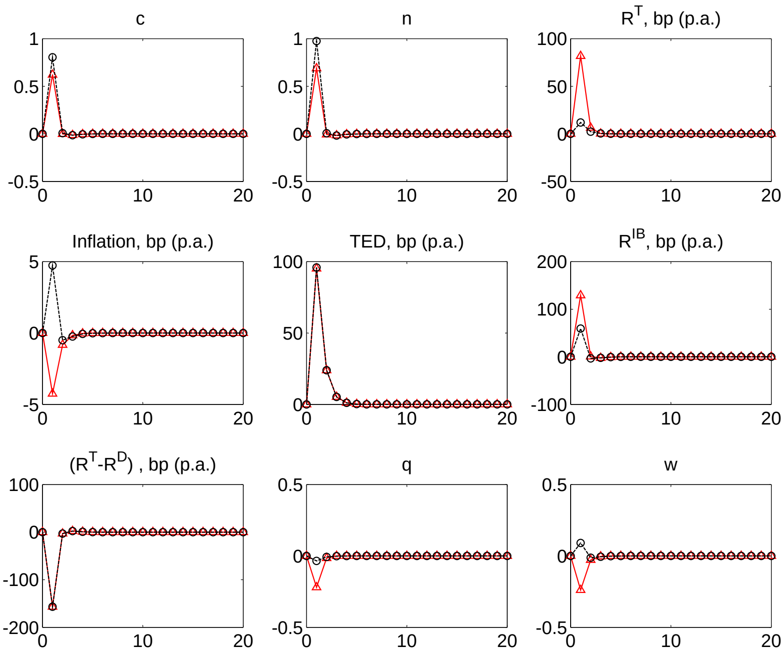


Figure 2.14: Impulse Responses to Counterfactual Banking Stress under Modified Taylor Rule
Note: The shock represents negative shock to $A_t^{\bar{b}}$ and positive shock to A_t^m and $A_t^{\tilde{m}}$ that generates 100 basis point elevation in TED with a modified Taylor rule that responds to elevations in the $R_t^L - R_t^D$ spread. The red triangle solid line represents the modified rule and the circle dashed line represents a standard Taylor rule. All interest rates and spreads are reported in basis points and annually.

Chapter 3

Macroeconomic Effects of Fluctuations in the Productivity of Banking

Four underlying sources of shocks are identified that fluctuate banking productivity: (a) banks' efficiency at monitoring households, (b) banks' efficiency at monitoring other banks, (c) the effective collateral value of capital, and (d) the supply of government securities relative to GDP. To quantify the stochastic properties of these shocks, I use the model's rational expectations solution along with time-series observations of banking and macroeconomic data in the U.S. from 1985 to 2015. Adverse banking shocks increase the opportunity cost of banking services, thereby worsening the implicit "banking services tax" on aggregate consumption. One standard deviation banking shocks impact macro-aggregates to a degree comparable to the standard TFP shock. Monetary policy best mitigates banking stress by reacting to the loan-deposit rate spread. Surprisingly, the modified rule outperforms the standard Taylor rule by cutting the interbank rate *less* aggressively in financial distress and better stabilizing inflation and aggregate output.

3.1 Introduction

Stability in the banking sector has been one of the main concerns of central banks around the world.[1] Yet, conventional models of monetary policy analysis do not account for the role of banks in providing transaction services. In particular, little research has evaluated macroeconomic consequences of productivity shocks in the banking system and their implications for monetary policy. I model the underlying structural shocks to the banking system in a macroeconomic framework, use historical observations to quantify their sizes, and evaluate their macroeconomic relevance.

[1]See comments by the Fed chair Yellen (2014), the previous Fed Chairman Bernanke (2015) and the annual report of the Bank for International Settlement (2015).

I then explore how effective monetary policy could mitigate the macroeconomic consequences of banking shocks when the central bank reacts to alternative measures of banking stress.[2]

The model features an otherwise standard representative-agent infinite-horizon macroeconomic framework with goods production augmented with a banking sector. In this model, the household demands bank deposits to pay for goods from other households.[3] To acquire bank deposits, the household sells government bonds to a bank (operated by another household) or borrows funds from the bank against its collateral value and future income prospects (the loan period).

The bank, on the other hand, monitors and evaluates the effective collateral value of the household's assets, provided by government bonds and capital, and its ability to repay borrowed funds. During the loan repayment period, the banks must provide payment services to households on a moment's notice. In the model, to make payments, a bank borrows from other banks in the interbank market. Therefore, an interbank creditor monitors and evaluates the bank's ability to repay, taking into consideration the borrowing bank's government bond holdings relative to the amount it borrows. Accordingly, government bonds provide collateral services to banks as well.

Disturbances in the banking system impact the macroeconomy by fluctuating the opportunity cost of holding bank deposits per unit of consumption. This fluctuation drives a wedge between marginal utilities of consumption and income, and acts like an implicit "banking services tax" on aggregate consumption.[4] The banking tax appears in the Euler equation and affects the intertemporal choices of households. During a period of banking stress, shocks to the banking system result in lower productivity of banking and elevate the banking tax. When households expect the banking tax increase to be temporary, they defer consumption, thereby causing recession in the aggregate economy.

As a result, in this model, four underlying sources fluctuate productivity of the banking system: a) banks' efficiency at monitoring households, b) banks' efficiency at monitoring other banks, c) the effective collateral value of capital relative to government bonds, and d) the supply of government securities relative to GDP. This paper's main objective is to quantify macroeconomic implications of fluctuations in productivity of banks in these four dimensions.

To quantify the macroeconomic effects of banking shocks, it is important to determine the size of the initial impulse, which depends on the standard deviation of the innovation term, and its persistence level. To this end, I generate model-implied time-series of the underlying sources of fluctuations in the banking system's productivity

[2]I distinguish between the concepts of *banking stress* as involving normal fluctuations in the productivity of banking and *banking distress* that reflects more extreme cases of banking stress.

[3] The model builds on the model developed in our earlier work Bazarbash and Goodfriend (2013).

[4]The banking tax is reminiscent of Svensson (1985) in a narrow liquidity context.

over the sample period. Specifically, I use the rational expectations solution of the log-linearized model in conjunction with quarterly observations of four banking variables in the U.S. from 1985 to 2015. These variables are the TED spread (EuroDollar-Treasury spread), the government securities holdings of banks per dollar of deposits, the real return of government bonds, and the supply of government securities relative to GDP.

Unlike shocks in the real sector, I find shocks in the banking sector are short-lived but have large magnitudes. As a result, they induce significant fluctuations in the banking services tax and therefore in aggregate consumption. The real impact of banking shocks turns out to be in the same order of magnitude as a standard goods productivity shock. Moreover, negative banking shocks elevate the markup and create deflation. Consequently, fluctuations in the productivity of the banking system significantly contribute to fluctuations in the real sector.

The above results are based on a standard Taylor rule assumption for monetary policy. To mitigate the adverse consequences of shocks to banking, I evaluate the efficacy of modifying the standard Taylor rule to allow the central bank to react to a measure of banking stress. Among alternative interest rate spreads, the model suggests that variations in the "deposit spread" (the spread between the shadow total yield[5] and the deposit rate) perfectly captures variations in the banking tax. Indeed, simulations demonstrate that a policy rule that adjusts the interbank rate inversely with respect to movements in the deposit spread can fully offset the deflation caused by financial distress, regardless of its underlying source. Moreover, in the general equilibrium, the modified rule stabilizes inflation and output during financial distress by cutting the nominal interbank rate less aggressively than the standard Taylor rule. This is because households take the behavior of the central bank into account when forming their expectations and making their intertemporal consumption choices. In particular, during banking stress when households perceive the elevation in the banking tax to be temporary, they also expect that the central bank will adjust the interbank rate upward as the banking tax goes down. These two effects counteract in the Euler equation and households no longer defer consumption, unlike the standard Taylor rule that is not explicitly sensitive to financial distress.

However, this modified rule is not operational because the deposit spread is an unobservable variable in the model. Instead, I consider two alternatives: the policy rule that is sensitive to the TED spread, a widely regarded indicator of banking stress, and one that is sensitive to the loan-deposit rate spread. The TED spread-sensitive rule stabilizes inflation and output during banking stress. However, this policy rule does not exhibit a robust performance across different dimensions of banking stress. In

[5]The shadow total yield represents the risk-adjusted return on any asset held by households in the economy. The total yield on any asset is composed of an observable component (pecuniary return) and a non-observable component that accounts for the liquidity services provided by that asset to the households.

particular, in oder to fully stabilize aggregate prices, the optimal degree of the policy rule's sensitivity to the TED spread depends on the nature of the underlying shock to banking. The reason is that the TED spread moves more sharply in response to collateral supply shocks as opposed to monitoring efficiency shocks.

Unlike the TED spread, the loan-deposit rate spread mimics movements in the banking tax almost perfectly. As a consequence, as simulation results show, the central bank that commits to reacting to the loan-deposit spread variations can fully offset the deflation caused by banking stress, regardless of its underlying source.

Prior research that has studied monetary policy in the presence of financial frictions has assumed an ad hoc value for the size of shocks to the financial sector. For example, Goodfriend and McCallum (2007) analyze standard interest rate policy in response to a 1% innovation shock to the banking system, while assuming these shocks have a standard deviation of one. With this assumption, banking shocks turn out to be inconsequential for monetary policy purposes.[6] However, I show that data-implied values for standard deviation of banking shocks are much larger, thereby banking shocks matter for monetary policy purposes. Curdia and Woodford (2010) examine modifications of the standard Taylor rule that reacts to measures of financial distress in response to shocks that lead to a 4% increase in annual interest rate spreads. While they find an adjustment for credit spreads improves the Taylor rule, they conclude the optimal size of the adjustment depends on the source of the variation in credit spreads. This study adds more insight into these findings by focusing on the banking services tax mechanism in transmitting banking shocks to aggregate variables. As discussed earlier, if the central bank reacts to the loan-deposit rate spread, the optimal size of adjustment (sensitivity of the policy rule to variations in the spread) does not depend on the underlying source of disturbance in banking.

A similar line of research motivated by the recent financial crisis has explored the performance of unconventional monetary policy in response to disruptions in the financial sector (Gertler and Kiyotaki (2015 , 2010); Brunnermier and Sannikov (2014); Gertler and Karadi (2011); Gertler and Kiyotaki (2010); cf. Brunnermier, Eisenbach and Sannikov (2012)). Although these studies provide deep insight into various aspects of interaction between the financial sector and the macroeconomy, financial shocks are not quantified based on observations in their quantitative exercises.

Jermann and Quadrini (2012) provide a notable exception. They use financial and macroeconomic data to quantify financial frictions and show these shocks are important for aggregate output fluctuations. In addition to confirming the significant macroeconomic effects induced by banking shocks, this paper considers the role of monetary policy in mitigating these shocks and develops insight into what measure of banking stress the central bank should target.

[6] See the discussion by Gilchrist (2007) who carefully makes this point.

The rest of the paper is organized as follows. Section 2 develops the macroeconomic model with a banking sector and in particular discusses constraints that the banks face to make loans and provide payment services. Section 3 characterizes the macroeconomic equilibrium, focusing on the role of the banking services tax in translating banking shocks to aggregate variables and interest rate spreads. It also provides the conceptual framework to understand and interpret the quantitative exercises presented in section 5. Section 4 describes the calibration procedure in the log-linearized model and in particular the quantification of the stochastic processes of underlying shocks to banking productivity. Section 5 carries out the quantitative exercises of the paper, and discusses monetary policy in response to banking stress. Section 6 provides concluding remarks and summarizes the main findings of the paper.

3.2 Model

The macroeconomic model developed in this section incorporate a money and banking sector into an otherwise standard infinite-horizon representative-agent model with rational expectations and sticky prices. Each household owns a firm that operates in a monopolistically competitive production sector, and a bank that operates in a perfectly competitive banking sector. To provide banking services, banks engage in two loan markets: loans to households and interbank loans.

3.2.1 Households

The household seeks to maximize its expected lifetime utility from goods consumption and leisure time specified as,

$$E_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(c_t) + (1-\phi) \log(1-n_t^s)], \tag{3.2.1}$$

where β denotes the household's psychological discount factor, c_t its consumption of goods, and n_t^s its total supply of labor to the production and banking sectors at period t.

At each period, the household demands D_t^d number of nominal deposits for making payments to buy goods from other households. I assume a simple deposit-in-advance way,

$$V \frac{D_t^d}{P_t^A} \geqslant c_t, \tag{3.2.2}$$

where V is a constant parameter and represents the velocity of deposit circulation per unit of consumption, and P_t^A represents the aggregate level of prices. To consume c_t, the household needs to hold at least D_t^d/P_t^A deposits in real terms.

Further, the household receives pecuniary deposit interest rate R_t^D at the end of the period on its average deposit holdings during the period, which is reflected in its budget constraint (flow of funds constraint) given by,

$$\frac{D_{t-1}^d}{P_t^A}(1+R_{t-1}^D)+\frac{B_t^h}{P_t^A}+w_t n_t^s+\Pi_t^f+\Pi_t^b \geqslant \frac{D_t^d}{P_t^A}+\frac{B_{t+1}^h}{P_t^A(1+R_t^B)}+c_t+\tau_t. \tag{3.2.3}$$

The left side can be thought of as sources of income to the household that includes pecuniary return for holding deposits and government securities as of last period, compensation for labor supply at the market wage, w_t, and profits generated by its firm and bank expressed by Π_t^f and Π_t^b. The right side shows uses of income at the beginning of period t and incorporates household's allocation of funds for holding deposits, government securities, consuming goods and paying lump-sum tax τ_t to the government. Here, B_{t+1}^h expresses the face value of government securities to be redeemed at the beginning of period $t+1$ and discounted at the government bond rate R_t^B.

3.2.2 Firms

Each household operates a firm with a production technology in a good-producing sector with monopolistic competition. The firm's production and sales constraint is given by,

$$K_t^\eta\,(A_t n_t)^{1-\eta} \geqslant c_t^A\left(\frac{P_t}{P_t^A}\right)^{-\theta}, \tag{3.2.4}$$

Here A_t is the productivity of labor, n_t is labor employed by the firm, K_t is the capital stock from previous period, c_t^A is the aggregate demand for goods and P_t is the price that the firm sets. Price-setting is assumed to conform to the standard Calvo (1983) style. Therefore, at each period the firm adjusts its prices optimally at a fixed probability, otherwise sticks to its price as of the previous period. The left side represents the common Cobb-Douglas production technology. The right side specifies the downward-sloping demand for the firm-specific goods.

The firm's profit at period t is transferred to the household and it is given by,

$$\Pi_t^f = c_t^A\left(\frac{P_t}{P_t^A}\right)^{-(\theta-1)} + q_t(1-\delta)K_t - q_t K_{t+1} - w_t n_t, \tag{3.2.5}$$

where q_t denotes the price of capital at period t, and the fixed parameter δ represents the depreciation rate of capital. To simplify notation, I assume that the household manages the firm's payments, which is reflected in the constraint (3.2.2). Further, the household can pledge the capital against loans from the bank (elaborated in the problem of the bank).

3.2.3 Banks

Banks in the economy issue deposits (their only liabilities) that provide payment services to households. Assets of the bank are loans to households and government bonds. The balance sheet equality of the bank is accordingly given by,

$$L_t^h + \frac{B_{t+1}^b}{1+R_t^B} = D_t^s, \tag{3.2.6}$$

where L_t^h denotes loans that the bank makes to households at the beginning of period t and B_{t+1}^b is the face value of government bonds that a bank holds. D^s is the bank's supply of deposits. The balance sheet equality in this model can be interpret in the following way. When a bank decided to lend to a household or buy government bonds from a household, an equal amount of deposits will be *created* in the economy. From the household's perspective, the household *finances* deposits (that facilitate payments) by borrowing from the bank or selling government bonds to the bank.

To lend funds to the household, the bank monitors and evaluates the effective collateral value of the household's assets, provided by government bonds and capital, and its ability to repay borrowed funds. Therefore, the amount of funds that a household can borrow depends on its collateral and the intensity of monitoring by bank, which is specified by,[7],

$$\frac{L_t^h}{P_t} \leqslant \left(\frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + k_t q_t K_{t+1}\right)^{\alpha} (F_t m_t)^{1-\alpha}. \tag{3.2.7}$$

Here, $0 \leqslant k_t < 1$ shows the lower collateral productivity of capital relative to government bonds. m_t is the bank's monitoring effort and F_t represents bank's efficiency at monitoring households.[8]

Once deposits are created, the bank must provide payment services to households at a moment's notice. To capture the liquidity mismatch between the assets and liabilities of the bank, I assume that a bank makes payments by borrowing from the interbank market during the loan period. The interbank market allows for transfer of funds from banks with excess deposits (inflow of funds) to the banks with deficit deposits (outflow of funds). In the interest of tractability, I assume the average size of interbank loans that a bank need to borrow during the period is proportionate to

[7]The use of loan production technology is pioneered by Goodfriend (2005) and utilized most notably by Goodfriend and McCallum (2007) and Curdia and Woodford (2010).

[8]Note that the special case of fully collateralized loans corresponds to $\alpha = 1$. In that case, the inequality boils down to the familiar financial constraint $\frac{L_t^h}{P_t} \leqslant \frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + k_t q_t K_{t+1}$.

the size of its balance sheet up to ℓ and is determined at the beginning of the period according to,

$$L_t^{IB} = \ell D_t^s. \tag{3.2.8}$$

The parameter ℓ can be thought of as the circulation of deposits for making payments among households.

By analogy to household borrowing, to issue loan to the bank, an interbank creditor monitors the bank's ability to repay the interbank loan and its balance sheet composition. In particular, an interbank creditor monitors a bank with higher government bonds on its balance sheet less intensively. To capture these features, I assume the interbank loan technology is specified according to,

$$\frac{L_t^{IB}}{P_t^A} \leqslant \left(\frac{B_{t+1}^b}{P_t^A (1+R_t^B)} \right)^{\tilde{\alpha}} \left(\tilde{F}_t \tilde{m}_t \right)^{1-\tilde{\alpha}}. \tag{3.2.9}$$

Here, $\tilde{m}_t$ is the bank's labor employment to monitor other banks and $\tilde{F}_t$ represents its efficiency at monitoring other banks. The role of government bonds in the interbank loan technology reflects the implicit collateral services provided by government bonds to the bank.

In sum, to issue transaction-facilitating deposits, the bank is exposed to the following two constraints,

$$\left(\frac{B_{t+1}^h}{P_t^A (1+R_t^B)} + k_t q_t K_{t+1} \right)^{\alpha} (F_t m_t)^{1-\alpha} + \frac{B_{t+1}^b}{P_t^A (1+R_t^B)} \geqslant \frac{D_t^s}{P_t^A}, \tag{3.2.10}$$

$$\left(\frac{B_{t+1}^b}{P_t^A (1+R_t^B)} \right)^{\tilde{\alpha}} \left(\tilde{F}_t \tilde{m}_t \right)^{1-\tilde{\alpha}} \geqslant \ell \frac{D_t^s}{P_t^A}. \tag{3.2.11}$$

The bank's profit stream at period t is given by,

$$\Pi_t^b = \frac{D_t^s}{P_t^A} + \frac{B_t^b}{P_t^A} - \frac{D_{t-1}^s}{P_t^A}(1+R_{t-1}^D) - \frac{B_{t+1}^b}{P_t^A (1+R_t^B)} - w_t(m_t + \tilde{m}_t). \tag{3.2.12}$$

3.2.4 The First Order Conditions

The representative household's problem is, therefore, to maximize its expected lifetime utility (3.2.1) subject to the deposit-in-advance constraint (3.2.2), the flow of funds constraint (3.2.3), the goods production and sales constraint (3.2.4), the deposit creation constraint (3.2.10) and the deposit servicing constraint (3.2.11), taking price variables and interest rates as given. Suppose the Lagrange multipliers associated with these constraints are ν_t, λ_t, ξ_t, ψ_t and $\tilde{\psi}_t$ respectively.

Moreover, I define the total nominal risk-adjusted return on any asset held by households (the shadow total yield) as R^T_t, which satisfies

$$E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\right]\left(1+R^T_t\right)=1, \tag{3.2.13}$$

where $\pi_{t+1}=P^A_{t+1}/P^A_t-1$.

First order conditions for the representative household are,[9]

$$\partial c_t:\quad \frac{\phi}{c_t\lambda_t}=1+\frac{1}{V}\frac{\nu_t}{\lambda_t}, \tag{3.2.14}$$

$$\partial D^d_t:\quad 1=\frac{\nu_t}{\lambda_t}+\frac{1+R^D_t}{1+R^T_t}, \tag{3.2.15}$$

$$\partial D^s_t:\quad 1=\frac{\psi_t}{\lambda_t}+\ell\frac{\tilde{\psi}_t}{\lambda_t}+\frac{1+R^D_t}{1+R^T_t}, \tag{3.2.16}$$

$$\partial n^s_t:\quad w_t\lambda_t=\frac{1-\phi}{1-n^s_t-m^s_t-\tilde{m}^s_t}, \tag{3.2.17}$$

$$\partial n_t:\quad w_t=\frac{\xi_t}{\lambda_t}(1-\eta)A_t\left(\frac{K_t}{A_t n_t}\right)^{\eta}, \tag{3.2.18}$$

$$\partial m_t:\quad w_t=\frac{\psi_t}{\lambda_t}(1-\alpha)F_t\left[\frac{\frac{B^h_{t+1}}{P^A_t(1+R^B_t)}+k_t q_t K_{t+1}}{F_t m_t}\right]^{\alpha} \tag{3.2.19}$$

$$\partial \tilde{m}_t:\quad w_t=\frac{\tilde{\psi}_t}{\lambda_t}(1-\tilde{\alpha})\tilde{F}_t\left[\frac{\frac{B^b_{t+1}}{P^A_t(1+R^B_t)}}{\tilde{F}_t\tilde{m}_t}\right]^{1-\tilde{\alpha}} \tag{3.2.20}$$

$$\partial P_t:\quad \frac{\xi_t}{\lambda_t}=\frac{\theta-1}{\theta}\left(\frac{P_t}{P^A_t}\right), \tag{3.2.21}$$

$$\partial K_{t+1}:\quad 1=k_t\frac{\psi_t}{\lambda_t}\Omega^h_t+\frac{1}{1+R^T_t}E_t\left[\frac{q_{t+1}}{q_t}(1-\delta)+\frac{\eta}{q_t}\frac{\xi_{t+1}}{\lambda_{t+1}}\left(\frac{A_{t+1}n_{t+1}}{K_{t+1}}\right)^{1-\eta}\right], \tag{3.2.22}$$

$$\partial B^h_{t+1}:\quad 1=\frac{\psi_t}{\lambda_t}\Omega^h_t+\frac{1+R^B_t}{1+R^T_t}, \tag{3.2.23}$$

$$\partial B^b_{t+1}:\quad 1=\frac{\psi_t}{\lambda_t}+\frac{\tilde{\psi}_t}{\lambda_t}\Omega^b_t+\frac{1+R^B_t}{1+R^T_t}. \tag{3.2.24}$$

Here, $\Omega^h_t=\alpha\left[\frac{F_t m_t}{\frac{B^h_{t+1}}{P^A_t(1+R^B_t)}+k_t q_t K_{t+1}}\right]^{1-\alpha}$ and $\Omega^b_t=\tilde{\alpha}\left[\frac{\tilde{F}_t\tilde{m}_t}{\frac{B^b_{t+1}}{P^A_t(1+R^B_t)}}\right]^{1-\tilde{\alpha}}$ denote the marginal product of government debt (collateral) in producing loans to households and in producing interbank loans, respectively.

In the next section, I will discuss the conditions that govern the relationships between the money and banking sector and macroeconomic variables.

[9]See Appendix C.1 for derivation of these conditions.

3.2.5 Government

To complete characterizing the general equilibrium, we need to specify the government budget constraint and policies. At each period, the government budget constraint is given by,

$$g_t - \tau_t = \frac{B_{t+1}}{P_t^A(1+R_t^B)} - \frac{B_t}{P_t^A}, \tag{3.2.25}$$

where g_t is the government expenditure, which is normalized to zero. The fiscal authority is assumed to issue government debt according to,

$$\frac{B_{t+1}}{P_t^A(1+R_t^B)} = \bar{b}_t c_t. \tag{3.2.26}$$

I assume the behavior of monetary policy by the central bank follows a standard Taylor rule specified as,

$$R_t^{IB} = (1+\mu_1)\pi_t + \mu_2\, mc_t, \tag{3.2.27}$$

where μ_1 and μ_2 are weightings on the inflation rate and the output gap, which is represented here by the real marginal cost of producing goods. Later sections will further study modified versions of the Taylor rule that respond to interest rate spreads to reflect the central bank's concern for financial stability.

Finally, aggregate prices are assumed to adjust in the Calvo (1983) style specified as,

$$\pi_t = \beta E_t \pi_{t+1} + \kappa\, mc_t. \tag{3.2.28}$$

3.3 Macroeconomic Equilibrium

This section characterizes the macroeconomic equilibrium in the economy, focusing on the role of the banking tax in translating shocks to banking into the macroeconomy and interest rate spreads. Moreover, it develops a conceptual framework to understand and interpret the quantitative exercises of the later sections.

Definition Given the fiscal and monetary policy rules, a macroeconomic equilibrium is defined as an allocation[10] (c_t, D_t, n_t, m_t, $\tilde{m}_t$, B_{t+1}^h, B_{t+1}^b), prices (w_t, R_t^D, R_t^B, R_t^{IB}, P_t, q_t) and exogenous stochastic processes for (A_t, F_t, $\tilde{F}_t$, k_t, $\bar{b}_t$) so that the following conditions are satisfied: (1) each household makes optimal decisions, (2) the bank deposit market clears $D_t^s = D_t^d$, (3) the goods market clears, implying the aggregate resource constraint $K^\eta (A_t^n n_t)^{1-\eta} = c_t + \delta K q_t$, (4) the labor market clears $n_t^s = n_t + m_t + \tilde{m}_t$, (5) the government securities market clears $B_{t+1} = B_{t+1}^h + B_{t+1}^b$, and (6) symmetry in

[10]The capital stock is assumed to remain invariant at its steady state value K.

price setting holds, i.e. $P_t = P_t^A$. The full set of equilibrium conditions is provided in the appendix.

3.3.1 The Banking Services Tax

In the model, bank deposits pay lower interest than the shadow total yield in equilibrium. The spread between the shadow total yield and the deposit rate (henceforth "the deposit spread") reflects households' valuation of transaction services provided by deposits. It also reflects the total marginal cost of issuing deposits and providing payment services in the banking system. The deposit spread drives a wedge between the marginal utility of income and consumption in equilibrium, which inversely depends on the productivity of the banking system.

Combining household's consumption and demand for deposits conditions results in,

$$\frac{\phi}{c_t} = \lambda_t \left(1 + \frac{1}{V}\left(\frac{R_t^T - R_t^D}{1 + R_t^T}\right)\right). \tag{3.3.1}$$

Equation (3.3.1) shows that in equilibrium the marginal utility of consumption, ϕ/c_t, remains above the marginal utility of income, λ_t, because for any unit of consumption the household holds $1/V$ units of real deposits. Since the opportunity cost of holding a real dollar of deposits is given by the deposit spread, the expression $\frac{1}{V}\left(\frac{R_t^T - R_t^D}{1+R_t^T}\right)$ captures the opportunity cost of holding deposits per unit of consumption by households. As a result, it acts like an implicit tax on aggregate consumption, henceforth called the "banking services tax."[11]

Because the banking tax drives a wedge between the marginal utility of consumption and income at each period, short-term variations in the banking tax affect the households' intertemporal consumption choices. In particular, these choices follow,

$$E_t\left[\beta\frac{c_t}{c_{t+1}}\left(\frac{1 + \frac{1}{V}\left(\frac{R_t^T - R_t^D}{1 + R_t^T}\right)}{1 + \frac{1}{V}\left(\frac{R_{t+1}^T - R_{t+1}^D}{1 + R_{t+1}^T}\right)}\right)\frac{1}{1 + \pi_{t+1}}\right]\left(1 + R_t^T\right) = 1, \tag{3.3.2}$$

which is obtained by substituting (3.3.1) in (3.2.13). The Eurler equation now involves a new term that accounts for the relative intertemporal change in the banking tax. The log-linearized approximation of equation (3.3.2) is given by,

$$\hat{c}_t = E_t\hat{c}_{t+1} - \left(R_t^T - E_t\pi_{t+1}\right) + \frac{1}{V}\left(E_t\left(R_{t+1}^T - R_{t+1}^D\right) - \left(R_t^T - R_t^D\right)\right), \tag{3.3.3}$$

[11] The R^T specification and conceptual model of the banking tax was employed initially by Goodfriend (2005) and used in Goodfriend and McCallum (2007).

where as usual the hat symbol represents the relative deviation from the steady state value. Equation (3.3.3) can be thought of an otherwise forward-looking expectational IS relationship (in the three-equation canonical new Keynesian framework), which now includes a new expression that reflects the expected change in the banking tax. According to this relationship, when households expect the banking tax to decrease (e.g. banking stress perceived to be temporary), they defer consumption, which leads to recession in the aggregate economy.

At each period, the magnitude of the banking tax depends on the banking system's productivity to issue bank deposits and provide payment services. To illustrate the impact of underlying sources of fluctuations in banking productivity on the banking tax, I first show that the deposit spread is comprised of two components that account for the marginal costs of making loans to households and providing payment services. To this end, I define "the shadow interbank rate" as the interest opportunity cost of loanable funds to banks, which satisfies

$$1 = \frac{\psi_t}{\lambda_t} + \frac{1 + R_t^{IB,T}}{1 + R_t^T}. \tag{3.3.4}$$

Accordingly, the spread between the shadow total yield and the shadow interbank rate reflects the external finance premium in the model, to account for the total marginal cost of issuing loans to households. The external finance premium is captured by ψ_t/λ_t in the model, which reflects the shadow price of deposit creation constraint and conforms with the above interpretation.

As a result, the deposit spread is divided into: a) the marginal cost of issuing a real dollar of deposits in the banking system captured by $R_t^T - R_t^{IB,T}$, and b) the marginal cost of providing payment services by the banking system via interbank loans captured by $R_t^{IB,T} - R_t^D$.

The full marginal cost of making loans to households in the banking system is accounted for by the shadow total yield. This yield has three underlying components: a) the opportunity cost of loanable funds to a bank $R_t^{IB,T}$, b) the marginal cost of monitoring households (borrowers) by the bank $R_t^L - R_t^{IB,T}$, and c) the return to holding collateral by the household $R_t^T - R_t^L$. The last component accounts for the productivity of collateral to defray the cost of monitoring in the loan process, which can also be thought of as a rebate to the household due to pledging collateral. Because the share of collateral in the production of loans to households is α, the decomposition is expressed as,

$$R_t^T - R_t^L = \alpha \left(R_t^T - R_t^{IB,T} \right), \tag{3.3.5}$$

$$R_t^L - R_t^{IB,T} = (1 - \alpha) \left(R_t^T - R_t^{IB,T} \right). \tag{3.3.6}$$

To provide payment services for a dollar of deposits, banks need to borrow ℓ dollars of interbank loans (as also seen in equation (3.2.8)). Moreover, the total marginal cost of interbank borrowing is given by $\tilde{\psi}_t/\lambda_t$ in the model. As a result, the total cost of providing payment services per dollar of deposits is given by $\ell\tilde{\psi}_t/\lambda_t$. This is consistent with the optimal deposit supply condition.

For illustration purposes, assume that for ℓ fraction of their deposits, banks need to borrow interbank funds to provide payment services, and they pay $R_t^{D'}$ on those deposits. For the remaining deposits ($1-\ell$ fraction), they pay the shadow interbank rate.[12] The no-profit condition implies that in equilibrium $R_t^{D'}$ is lower than the shadow interbank rate by the total marginal cost of interbank borrowing $\tilde{\psi}_t/\lambda_t$.

The shadow interbank rate can be broken down into three underlying components: a) the $R_t^{D'}$ rate, b) the marginal cost of monitoring enforced by the interbank creditor, $R_t^{IB} - R_t^{D'}$, and c) the return for holding government bonds by the interbank borrower, $R_t^{IB,T} - R_t^{IB}$. The last component represents the effect of government debt holding by the borrowing bank on the intensity of monitoring by the interbank lender. The share of the borrowing bank's government debt holding in the production of interbank loans is $\tilde{\alpha}$, therefore,

$$R_t^{IB,T} - R_t^{IB} = \tilde{\alpha}\left(R_t^{IB,T} - R_t^{D'}\right), \tag{3.3.7}$$

$$R_t^{IB} - R_t^{D'} = (1-\tilde{\alpha})\left(R_t^{IB,T} - R_t^{D'}\right). \tag{3.3.8}$$

The average deposit rate used in the original model's specification is given by,

$$R_t^D = \ell R_t^{D'} + (1-\ell)R_t^{IB,T}$$

As a result,

$$R_t^{IB,T} - R_t^{IB} = \frac{\tilde{\alpha}}{\ell}\left(R_t^{IB,T} - R_t^{D}\right), \tag{3.3.9}$$

$$R_t^{IB} - R_t^{D} = \left(1-\frac{\tilde{\alpha}}{\ell}\right)\left(R_t^{IB,T} - R_t^{D}\right). \tag{3.3.10}$$

In what follows, I describe how the government bond rate, R_t^B is determined in the model to consistently value collateral services provided by government debt across households and banks.

[12] In this case, deposits act like loanable funds for the bank, because they are available for the bank to lend out over the loan period. This could be thought of as time deposit accounts that do not provide any transaction services during their period. The other type of deposits represent transaction deposits e.g. savings deposits for which the bank needs to provide payment services on a moment's notice.

3.3.2 Collateral Services Yield

Government debt and capital stock held by households provide collateral services against loans from banks. As a result, their risk-adjusted pecuniary return falls below the shadow total yield to reflect their collateral services premium. The optimal government debt holding by households follows,

$$R_t^T - R_t^B = \Omega_t^h \left(R_t^T - R_t^{IB,T} \right). \tag{3.3.11}$$

The left side represents the interest opportunity cost of holding government bonds to households. The right side shows households' valuation of collateral services provided by government bonds, which is the value of marginal product of collateral in loans from banks. Here, as defined earlier, Ω_t^h represents the productivity of collateral in loans to households, which is given by

$$\Omega_t^h = \frac{\alpha\, L_t^h / P_t}{\dfrac{B_{t+1}^h}{P_t^A (1 + R_t^B)} + k_t q_t K_{t+1}}. \tag{3.3.12}$$

Therefore, the marginal collateral services of government bonds is a decreasing function of the total effective collateral value of the household per dollar of loans.

Similarly, the return on capital stock in the goods production remains lower than the shadow total yield in equilibrium to reflect the collateral premium of capital stock. Since capital stock provides less collateral value relative to government debt, as captured by $k_t < 1$, the collateral services yield of capital is k_t times the collateral services yield of government debt. This is seen in the household's optimal choice for capital stock,

$$k_t \left(\frac{R_t^T - R_t^B}{1 + R_t^T} \right) + \frac{1}{1 + r_t^T} E_t \left[\frac{q_{t+1}}{q_t} (1 - \delta) + \frac{\eta}{q_t} \frac{\xi_{t+1}}{\lambda_{t+1}} \left(\frac{A_{t+1} n_{t+1}}{K_{t+1}} \right)^{1-\eta} \right] = 1, \tag{3.3.13}$$

which shows that the risk-adjusted return to capital stock is lower than the shadow total yield by the marginal collateral services provided by capital.

Equilibrium conditions (3.3.11) and (3.3.13) govern the collateral composition of the household. Consider a household with a given amount of loan and collateral value. The productivity of collateral is thus determined by (3.3.12), which determines the collateral services yield of government debt.[13] An individual household (who takes prices as given) has the option of increasing its government bond holding and simultaneously decreasing its capital stock by $1/k_t$ to maintain the initial collat-

[13] Note that the marginal product of collateral is α times the loan to value ratio in the model, and unlike other setups it is not constrained to be a fixed value.

eral value, without affecting the collateral services yield of government debt. However, lower capital stock increases capital's goods productivity in the next period, and thereby its physical return. Since the collateral return remains invariant, the total return of the household's capital stock increase. The optimal collateral composition is obtained when equation (3.3.13) holds to set the total return on capital equal to the shadow total yield.

Let's now turn to collateral demand in the banking system. The optimal condition for government debt demand by banks implies,

$$R_t^T - R_t^B = \left(R_t^T - R_t^{IB,T}\right) + \frac{\Omega_t^b}{\ell}\left(R_t^{IB,T} - R_t^D\right). \tag{3.3.14}$$

This equation shows that in equilibrium the opportunity cost of holding government debt, i.e. the government bond spread, on the left side equals the marginal benefits provided by government debt on the balance sheet of banks on the right side. It shows that government debt is valuable on the balance sheet of banks for two reasons. First, the bank saves on the external finance premium costs, $R_t^T - R_t^{IB,T}$, because instead of making loans to issue deposits, it now buys government debt from households to create deposits. Second, the bank saves on the cost of interbank borrowing, because government debt held by the interbank borrower defrays the cost of monitoring by the interbank lender. The value of marginal product of government debt in interbank loans is given by the productivity of collateral Ω_t^b multiplied by the total marginal cost of interbank loans $1/\ell\left(R_t^{IB,T} - R_t^D\right)$.

[Figure 1]

From an individual bank's point of view who takes interest rates as given, higher government bond holding implies lower marginal product of collateral in interbank loans given by,

$$\Omega_t^b = \tilde{\alpha}\ell\frac{D_t}{\frac{B_{t+1}^b}{1+R_t^B}}.$$

Therefore, the bank chooses its optimal government debt holding relative to deposits to satisfy (3.3.14).

The government bond spread is determined in equilibrium to clear the market for collateral services, i.e. the total supply of government debt equals the demand for government debt by households and banks. Figure 3.1 displays equilibrium in the market for collateral services from the banks' perspective. The demand reflects banks' valuation of collateral services from government debt, which is decreasing in the government debt holdings of banks as discussed above. The supply curve represents the total supply of government debt net of households' holdings of government debt, i.e.

$B_{t+1} - B^h_{t+1}$. The supply curve is upward sloping, because households' demand for government debt is inversely related to the collateral services yield, while the total supply is exogenous.

The discussion in the next section demonstrates how exogenous sources of the productivity of banking services shift the supply and demand curves as displayed in Figure 3.1.

3.3.3 Sources of Banking Tax Fluctuations

Four exogenous sources affect productivity of banking in the model: a) the efficiency of banks at monitoring households F_t, b) the efficiency of banks at monitoring other banks $\tilde{F}_t$, c) the effective collateral value of capital stock k_t, and d) the supply of government debt relative to aggregate consumption $\bar{b}_t$. A drop in each of these sources leads to stress in the banking system.

The components of the deposit spread can be expressed in terms of the opportunity cost of collateral and wage (marginal factor costs) as follows,

$$R^T_t - R^{IB,T}_t = \left(\frac{R^T_t - R^B_t}{\alpha}\right)^{\alpha} \left(\frac{w_t/F_t}{1-\alpha}\right)^{1-\alpha}, \tag{3.3.15}$$

$$R^{IB,T}_t - R^D_t = \ell \left(\frac{R^{IB,T}_t - R^B_t}{\tilde{\alpha}}\right)^{\tilde{\alpha}} \left(\frac{w_t/\tilde{F}_t}{1-\tilde{\alpha}}\right)^{1-\tilde{\alpha}}. \tag{3.3.16}$$

Consider the stress in the banking system that arises because banks become less efficient at monitoring households (a drop in F_t). This increases the effective factor cost of monitoring, w_t/F_t, thereby increasing the bank's marginal cost of producing loans to households. Consequently, the marginal collateral services of government debt exceeds the opportunity cost of holding government debt for households, which results in increased households' demand for collateral. The supply curve in Figure 3.1 shifts up, causing the opportunity cost of holding government bonds by banks to exceed the collateral services yield of government bonds to banks (as seen in (3.3.14)). Banks become willing to supply government bonds to households who demand collateral, and the collateral market clears at a higher collateral services yield.

In sum, the drop in F_t increase the marginal cost of creating deposits directly, the initial effect of which is alleviated because households purchase government debt from banks. Because banks' asset position in government debt is weakened, there is an indirect effect on the marginal cost of providing payment services. Both effects lead to a widened deposit spread and therefore the higher banking tax.

Now, consider banking stress in which banks become less efficient at monitoring other banks (a drop in $\tilde{F}_t$). In this case, a similar sequence of effects happens yet starting from the interbank market. Lower efficiency of interbank monitoring increases the effective factor cost of monitoring other banks, $w_t/\tilde{F}_t$, and raises the marginal cost of producing interbank loans. Banks' valuation of collateral services exceeds the opportunity cost and they demand for government debt goes up. The reverse happens for households and they supply government bonds to banks. This is summarized by an upward shift in the demand curve in Figure 3.1.

In case of the drop in $\tilde{F}_t$, the marginal cost of providing payment services primarily rises, for which banks respond by strengthening their balance sheets by holding higher government debt. The reduction in the collateral held by households along with elevated opportunity cost of collateral result in higher marginal cost of creating deposits. The deposit spread and hence the banking tax go up.

Finally, banking stress could emerge because of a drop in the supply of collateral. A drop in the effective collateral value of capital stock (drop in k_t) initially reduces households' effective collateral holdings, thereby raising the productivity of collateral. According to (3.3.11), households demand higher collateral, which in turn shifts the supply curve up in Figure 3.1. Banks sell government bonds to households, and the opportunity cost of collateral goes up in equilibrium. A similar chain of effects go through in the case of a contraction in the supply of public collateral $\bar{b}_t$.

Banking stress resulting from collateral contraction works through elevating the opportunity cost of collateral. Both households and banks end up holding less collateral in equilibrium, which implies higher marginal cost of creating and issuing deposits. The above discussion shows that if the ultimate increase in the collateral services yield is equal between the monitoring efficiency shocks and collateral supply shocks, the effect of the former on the banking tax is stronger than the latter because of the difference in effective factor cost of monitoring.

3.4 The Calibration Procedure

This section shows that a plausible calibration of model parameters exists, which reasonably conforms with observations. Model parameters are grouped into two sets. Under the standard approach to calibration, the first set are calibrated using steady state targets, some of which are typical in the literature. The second group includes parameters that govern the stochastic evolution of exogenous disturbances in the model and hence cannot be calibrated using steady state targets. For these, I develop a methodology that uses numerical methods in conjunction with time-series data.

3.4.1 Balanced Growth Equilibrium

The calibration presented in this section assumes the economy evolves around a zero-inflation balanced-growth equilibrium with common growth rates for labor productivity in the production and banking sectors. This assumption implies that technological progress impacts the production and banking sectors alike. Further, I assume the stochastic processes of disturbances follow an autoregressive process with one period lag. Specifically,

$$z_t = (I - \Phi)\bar{z} + \Phi z_{t-1} + \Sigma\ \varepsilon_t, \tag{3.4.1}$$

where z_t is the vector of detrended exogenous stochastic terms in the model. In particular, $z_t = \left[A_t, \bar{b}_t, F_t, \tilde{F}_t, k_t\right]'$.[14] Moreover, I is the identity matrix, and Φ is the diagonal matrix representing AR(1) persistence parameters. ε is a vector of standard normal innovation terms. The diagonal matrix Σ includes the standard deviations associated with each shock.

A balanced growth path equilibrium is one on which the innovation terms ε_t remain at zero. As a consequence, on the balanced growth path n_t, m_t, $\tilde{m}_t$, w_t, q_t, R^T_t, R^L_t, $R^{IB,T}_t$, R^{IB}_t, R^B_t and R^D_t remain invariant (at their steady state values). Moreover, c_t, D_t, B^h_{t+1}, B^b_{t+1} and K_{t+1} grow at the economy's growth rate γ, and λ_t shrinks at this rate.

3.4.2 Calibrated Parameters in the Steady State

In addition to the parameters governing the stochastic behavior of the model (discussed in the next section), there are fourteen parameters that need to be specified (see Table 3.1). Six of these appear in macroeconomic models without money and banking. For these, I use values commonly found in the literature. The discount factor is set to $\beta = 0.99$ and the labor augmenting technology grows at an annual rate of 2% corresponding to $\gamma = 0.005$ per quarter. Accordingly, the real annual value of the shadow total yield, $R^T = (1+\gamma)/\beta$, is 6% at the steady state. The utility weight of consumption is ϕ is 0.4 and leisure 0.6 to yield 1/3 of total hours for employment in production and banking. In the goods production, it is assumed that the share of capital is $\eta = 0.36$ and the elasticity of goods sales is $\theta = 11$ to yield a markup of 1.1. Moreover, capital is assumed to depreciate at an annual rate of 10 percent implying $\delta = 0.025$.

[Table 1]

The sample used to calibrate the non-standard parameters of the model includes U.S. banking and macroeconomic data from 1985 to 2015 at a quarterly frequency. I start from 1985 to study the period since the so-called "Great Moderation" during which the Taylor rule reasonably represented the interest policy of the central bank. The sample extends to the most recent data available at the time of writing the paper.

[14]Banks' efficiency at monitoring households and other banks, like goods productivity have a trend growth, while k_t and $\bar{b}_t$ are trendless.

Two parameters indicate the aggregate stocks of money and government debt. The velocity of money circulation per dollar of GDP was $V = 0.48$ using M2 data. The supply of government securities relative to GDP is constructed by data for domestic private sector holdings of Treasuries and Agencies excluding insurance and money market holdings[15].

The six banking parameters in the model, F, α, k, $\tilde{F}$, $\tilde{\alpha}$ and ℓ, are jointly calibrated so that the steady state solution matches average observations of six banking variables (see Table 3.2). The TED spread (variable 1) and banks' holding of government debt relative to deposits (variable 2) represent the banking system's demand for collateral services. The three-month T-bill rate (variable 3) indicates the collateral valuation of government debt by households. The external finance premium (variable 4) implies the marginal cost of creation of deposits, and the deposit rate (variable 5) indicates the marginal cost of servicing deposits. The share of employment in the banking sector relative to total employment (variable 6) shows how much labor was absorbed by the banking system.

[Table 2]

Table 3.2 reports the target values of the banking variables. The values for the TED spread, bank holdings of government securities per dollar of deposits, the real three-month Treasury-bill rate and the share of labor employed by depositories relative to total employment are their averages over the sample period. Moreover, the external finance premium is targeted to 2% in keeping with the Macro-Finance literature.[16] The average real deposit rate on all bank deposits represents the weighted return on all deposits.[17]

As can be seen in Table 3.2, the benchmark calibration has successfully matched the sample averages.[18] Furthermore, the banking parameters compare favorably with calibration of Goodfriend and McCallum (2007). The loan production is specified in their framework as

$$\frac{L^h}{P} = \mathcal{F} \cdot \left(\frac{B^h}{1 + R^B)} + kK \right)^{\alpha} m^{1-\alpha}.$$

Goodfriend and McCallum calibrate $\mathcal{F}$, α and k to 9, 0.65 and 0.20 respectively. Their framework, however, does not explicitly model interbank loans. In our benchmark cal-

[15]Data come from the flow of funds tables L.209 and L.210

[16]For a discussion of alternative measures of the external finance premium, see De Graeve (2008).

[17]Data for banking variables are based on Table H.8 release of the Federal Reserve Board of Governors that entails assets and liabilities of all commercial banks in the U.S. and interest rates are from Table H.15 of the same source. Banking employment data is obtained from FDIC website and total employment from the Bureau of Labor Statistics.

[18]It should be noted that as discussed in the previous section, the observed deposit rate aligns with the definition of transaction deposit rate $R^{D'}$, which is 1.26% and aligns with the observed average deposit rate.

ibration, the corresponding parameter values for the efficiency of monitoring households and other banks are 24 and 26, respectively.[19] A stark difference between calibrations is the lower effective collateral value of capital stock. Two reasons explain this deviation. First, the supply of government securities in this paper is almost twice as large as in Goodfriend and McCallum's calibration (1.06 compared with 0.56). Second, the government bond rate is lower in this paper because government debt is also valued in interbank loans (1% compared with 2.1%). This calls for a larger collateral services yield at the steady state, which is inversely related to the total collateral in the economy.

Now that we have calibrated the fourteen parameters, we can evaluate the steady-state implications for aggregate and banking variables. Table 3.3 reports the steady-state solution of the endogenous variables of the model. First consider the allocation of hours worked. Total available working time is close to $1/3$ as desired. The ratio of time worked in banking accounts for only 1% of the total hours worked, indicating that fluctuations in the banking employment due to banking shocks cannot induce a significant macroeconomic effect. Moreover, banks employ almost 10 times more hours to monitor households compared with monitoring other banks. This is consistent with the fact that banks can develop strategic partnerships with other banks (unlike with non-bank borrowers) as demonstrated by the tiering phenomenon in the interbank market (see Craig & Von Peter (2014)). These partnerships are possible because in the interbank market, a bank is generally both a lender and borrower as opposed to loans to households, in which the bank is only the lender.

[Table 3]

Under the benchmark calibration, we can infer the composition, stock and productivity of collateral that plays a key role in the functioning of the banking sector in the model. Collateral is composed of government debt and capital stock. The annualized steady-state capital output ratio is 2.72, which is in an acceptable range. Given that the q–price of capital equals 1 at the steady state, the effective collateral value of capital stock relative to quarterly consumption is 0.11, accounting for roughly 10% of total collateral in the economy. The rather low collateral services provided by capital is consistent with the fact that banks specialize in information-sensitive lending, as opposed to other collateral-intensive types of loans such as mortgage or auto. Productivity of collateral in both of the loan markets is roughly 1.30. The high productivity of collateral results in households paying 2.25% p.a. lower loan rate and banks paying 0.5% lower relative on their interbank borrowing.

The steady state solution demonstrates the significant effect of costly banking services on aggregate variables. In particular, the banking services tax is 9.1% annually.

[19] In effect, the corresponding $\mathcal{F}$ value is given by $F^{1-\alpha}$ in this paper's specification.

To illustrate the significance of the banking tax, Table 3.3 also reports the solution of the model with free banking. Relative to the free-banking economy, aggregate consumption is lower by 1.7% per quarter and employment is lower by 1.8%. The stock of capital in the benchmark calibration is lower by 1.3%. Two opposing forces determine the capital stock. First, households demand lower capital as a production factor because of lower production. Conversely, households demand higher capital stock for its collateral services. The first effect is stronger resulting in a net decline in the capital stock.

3.4.3 The Calibration of Stochastic Processes for Banking Shocks

The steady-state solution cannot be used to calibrate the parameters governing the stochastic process of shock terms, i.e. Φ and Σ. Instead, I infer the values of shock terms by using the rational expectations solution of the calibrated log-linearized model in conjunction with observations for banking variables. Since the persistence parameters affect the solution of the model, I appeal to a fixed point argument to ensure consistency.

The set of long-linearized equations of the model is presented in Appendix C.3. Denoting the vector of endogenous variables (in log deviations from the steady state) by y_t, this system is summarized by

$$y_t = A\ E_t y_{t+1} + D\ z_t. \tag{3.4.2}$$

By the method of undetermined variables, the model's rational expectations solution is conjectured to adopt the form

$$y_t = \Gamma\ z_t, \tag{3.4.3}$$

where z_t follows (3.4.1). Substituting $E_t y_{t+1} = \Gamma \Phi z_t$ in (3.4.2) implies that Γ should satisfy,

$$\Gamma = A \Gamma \Phi + D. \tag{3.4.4}$$

The solution for Γ depends on the values of A, D, and Φ. Matrices A and D depend on the steady state solution of the model and the parameters that were calibrated using the steady state solution. However, we have not yet determined Φ. If the time-series data of shock terms were available, Φ could be directly estimated.[20] On the other hand, to generate model-implied shock term using data, we need to know Γ.

Among shock terms, values of $\bar{b}_t$ could be directly generated by observations for the government debt supply relative to GDP. Moreover, as is standard in the real business cycle literature, the goods productivity shock values at each date is found using

[20]The time-series of shock terms could not be directly generated using loan production technology equation, because data for bank monitoring is not available over the sample period.

Solow residuals.[21]

The model's solution for banking variables is, therefore given by

$$y_t^b = \Gamma_A^b \log(A_t) + \Gamma_{\bar{b}}^b \log(\bar{b}_t/\bar{b}) + \Gamma_F^b \log(F_t/F) + \Gamma_{\tilde{F}}^b \log(\tilde{F}_t/\tilde{F}) + \Gamma_k^b \log(k_t/k), \quad (3.4.5)$$

where y^b collects observables (in log deviations) for a) the TED spread, b) the government debt holding of banks relative to deposits, and c) the three-month T-bill rate.[22]. From (3.4.5), the vector of banking shocks $z_t^b = \left[\log(F_t/F)\ ,\ \log(\tilde{F}_t/\tilde{F})\ ,\ \log(k_t/k)\right]$ is found as,

$$z_t^b = \Gamma^{b^{-1}}\left[y_t^b - \left(\Gamma_A^b \log(A_t) + \Gamma_{\bar{b}}^b \log(\bar{b}_t/\bar{b})\right)\right] \quad (3.4.6)$$

However, Γ^b is undetermined in (3.4.6), because it depends on persistence parameters of banking shocks. Therefore, I use persistence values such that the model-implied values for z_t^b also have the same persistence.

The quantification method involves the following steps:

1. Select an initial value for persistence parameters of banking shock terms Φ_0^b.

2. Using the benchmark calibration and the steady state solution along with Φ_0^b, solve for Γ in (3.4.4).

3. Produce time series of z_0^b over the sample according to (3.4.6).

4. Estimate the persistent parameters of z_0^b and denote by $\hat{\Phi}_0^b$.

5. If the difference between Φ_0^b and $\hat{\Phi}_0^b$ is larger than a desired threshold, return to step 1 and replace Φ_0^b with $\hat{\Phi}_0^b$.

Table 3.4 reports the values of parameters that govern the stochastic components of goods productivity, government debt (collateral) supply and three dimensions of banking productivity in the model. Under an autoregressive of order one specification, the statistical properties of the goods and banking productivity processes are influenced by the serial correlation parameter ρ and the standard deviations of the zero mean innovations σ. For example, the autocovariance of $\log(A)$ with its own value by j periods is given by $\rho_A^j \sigma_A^2/(1-\rho_A^2)$. Therefore, higher values of ρ and σ imply higher variability in the shock term. These properties will be important in the behavior of the economy in response to an impulse shock to each source.

[Table 4]

[21]The goods productivity shock A_t represents the labor augmenting shock and enters the (log-linearized) production technology as $\hat{y}_t = \eta\hat{K}_t + (1-\eta)\left(\hat{n}_t + \log(A_t)\right)$, which is slightly different from the more conventional specification of $\hat{y}_t = \log(A_t) + \eta\hat{K}_t + (1-\eta)\hat{n}_t$ up to a multiplier $1-\eta$.

[22]To be precise, y^b contains absolute deviation of the TED spread and the government bond rate from their steady state values, and the fractional deviation of banks' government debt holdings relative to deposits from its steady state value.

Table 3.4 paints a somewhat different picture for the stochastic properties of banking shocks compared with real shocks. The calibrated model calls for high variability and low persistence (reflected by short half-lives) of banking shocks. Specifically, (3.4.1) can be rewritten for each shock as,

$$z_{i,t} = (1 - \rho_i)\bar{z}_i + \rho z_{i,t-1} + \sigma_i \varepsilon_{i,t}, \tag{3.4.7}$$

where ρ_i represents the shock-specific persistence parameter (the second column in Table 3.4) and σ_i is the shock-specific standard deviation of the innovation term (the fifth column in Table 3.4). Moreover, ε_t is the innovation term that follows a standard normal distribution.

The standard deviations reported in Table 3.4 can accordingly be interpreted as follows. The impact of a 1% innovation shock ε_t, to the goods productivity (A_t) is amplified by its standard deviation to 1.2%. Similarly, the impact of a 1% innovation shock to the supply of government debt collateral relative to GDP ($\bar{b}_t$) is 2.3%. However, a unit innovation shock impacts banking shocks F_t, $\tilde{F}_t$, and k_t by 30%, 41%, and 73%, respectively.

The standard deviations of banking shocks are large because they are quantified to produce the high variability of the observed banking variables over the sample period. Specifically, the standard deviations of the TED spread and the real government bond rate were 46 and 182 basis points, which are large when compared with their averages of 57 and 93 basis points. Moreover, the standard deviation of log of banks' government debt holding per dollar of deposits was 0.17, which implies a 3.6% point deviation from its steady state value of 21.2%.

By relying on observations of banking variables, the methodology used in this section produced a concrete quantification of the stochastic properties of shocks in the model. The next section will use these properties to conduct quantitative exercises of the paper. Specifically, it will study the impulse responses of the calibrated log-linearized economy to a unit innovation shock to various sources of uncertainty in the model.

3.5 Quantitative Analysis

In this section, I use the calibrated log-linearized model to address the quantitative questions of the paper. My first objective is to quantitatively evaluate the macroeconomic impact of banking stress simulated by one standard deviation shocks to different dimensions of banking productivity. It turns out that by raising the banking tax, banking shocks induce substantial effects on aggregate output, employment and cause deflation. Motivated by this finding, I then explore the role for monetary policy to mitigate these effects. In particular, I examine whether in addition to responding to the output gap and inflation (as the standard Taylor rule suggests), the central bank should react to a measure of banking stress. I then investigate among the several interest rate spreads that the model generates endogenously, which one the central bank should use in its monetary policy rule to most effectively mitigate banking stress.

3.5.1 The Impact of Banking Shocks on Aggregate Variables

Figure 3.2 reports impulse responses of key variables to one standard deviation shocks to goods and banking productivity. The policy rule is assumed to follow the standard Taylor rule as specified by (3.2.27), and the values of standard deviation and persistence parameter for each shock is set according to Table 3.4.

[Figure 2]

A General Description of the Transmission Mechanism of Banking Shocks

Banking shocks induce significant effects on aggregate consumption, employment and inflation, as depicted in Figure 3.2. In particular, a negative shock to banks' efficiency at monitoring households (simulated by a drop in F), depresses aggregate consumption approximately the same as an adverse goods productivity shock. In addition, it reduces employment and creates deflation. Like other banking shocks, the model attributes these effects to the elevated banking tax effect. The higher a shock elevates the banking tax, the stronger is the impact on real variables.

The banking tax channel is seen by banking shocks' small effect on the total yield, yet substantial impact on the deposit spread in contrast to the goods productivity shock. In other words, even though banking shocks do not affect the shadow total yield, they still affect households' intertemporal choices of consumption and leisure by temporarily elevating the banking tax. For example, in response to a transient negative shock to F , the deposit spread elevates to account for the costly creation of deposits and provision of payment services. Hence, households experience a sudden elevation of the banking tax in the impact period and predict the initial effect to taper over time, and therefore defer consumption. The intertemporal effect depresses current aggregate demand for goods. In response, firms shrink their production scale, and lower their demand for labor and capital. Reduced factors demand result in lower wage and q price of capital. The resulting diminished marginal cost of goods elevates the markup, to which firms react by lowering prices (deflation) in order to restore the profit maximizing markup. The transmission mechanism of other banking shocks works similarly.

The model's quantitative predictions for the effect of the F shock on macroeconomic variables are as follows. Under the benchmark calibration, the shock results in 0.6% quarterly reduction in aggregate consumption, 0.8% lower employment and 1.5% points annual deflation. We see that the F shock leaves a stronger impact on aggregate variables among other banking shocks, by elevating the annual banking tax by 2.25% points in the impact period (compare to its steady state value of 9%).

Shock to Banks' Efficiency at Monitoring Households

The responses of banking variables to each banking shock reveal the underlying mechanics of how the shock affects banks' productivity. In particular, the F shock lowers banks' productivity of making loans to households, resulting in higher valuation of collateral services by households, thereby higher opportunity cost of banks' government debt holding (elevated TED spread in Figure 3.2). Banks react by releasing collateral to households (lower B^b/D). The flow of collateral from banks to households decreases households' collateral productivity (reduced Ω^h) and increases the marginal product of banks' collateral against interbank loans (elevated Ω^b). As a result of weakened balance sheet position of banks, interbank lenders monitor borrowing banks more intensively, which translates into elevated marginal cost of providing payment services. Therefore, both components of the deposit spread go up leading to an elevated banking tax.

Shock to the Collateral Efficiency of Capital Stock

The negative shock to F implies a backward shift in the collateral supplied to the banking system in Figure 3.1, because households absorb higher collateral resulting from the negative F shock. The drop in the collateral supplied to the banking system could also be attributed to a drop in the collateral efficiency of capital stock relative to government bonds (simulated by a drop in k). A negative k shock shrinks the households' effective collateral value, thereby increasing the marginal product of household collateral (elevated Ω^h). Higher valuation of collateral by households is reflected by elevated opportunity cost of collateral for banks (higher TED spread). Banks reduce their holding of government debt, which results in elevated marginal product of banks' collateral (higher Ω^b). Therefore, with a k shock (unlike the F shock), marginal product of collateral increases for both banks and households. Weaker collateral holding against loan (higher loan-to-value ratios) increases banks' marginal cost of issuing loans to households and other banks. As a result, the banking tax goes up.

Comparing Banks' Monitoring Efficiency and Capital's Collateral Efficiency Shocks

Under the benchmark calibration, banking stress induced by a negative F shock induces stronger real effects than a k shock. Moreover, at face value the k shock seems to be more significant than the F shock as measured by the standard deviations ($\sigma^k = 74\%$ while $\sigma^F = 30\%$). To compare the real effect, however, we should examine how these two shocks impact the productivity of loans made to households by banks. The loan technology in the log-linearized form is given by,

$$\hat{L}_t^h - \hat{P}_t = \frac{\alpha \frac{B^h}{1+R^B}}{\frac{B^h}{1+R^B} + kK} \left(\hat{B}_{t+1}^h - R_t^B - \hat{P}_t \right) + \frac{\alpha k K}{\frac{B^h}{1+R^B} + kK} \left(\hat{q}_t + \hat{k}_t \right) + (1-\alpha) \left(\hat{F}_t + \hat{m}_t \right). \tag{3.5.1}$$

Therefore, the elasticity of loans with respect to banks' monitoring efficiency is $1-\alpha$, and with respect to collateral efficiency of capital is $\alpha kK / \left(\frac{B^h}{1+R^B} + kK \right)$. These elasticities are 0.45 and 0.08 under the benchmark calibration. Hence, the direct effect of one-standard deviation shocks to F and k on loans to households are 13% and 6%. Therefore, the model suggests that collateral drainage shocks induce less severe impact on the economic activity as opposed to shock to banks' monitoring efficiency (e.g. emergence of an uncertain credit environment, which renders ensuring credibility of borrowers complicated).

Shock to Government Debt (Collateral) Supply Relative to GDP

Banking stress could be caused by a contraction in the supply of government debt relative to GDP (simulated by a negative $\bar{b}$ shock) following a cut in government borrowing. Contraction in the collateral supply causes both households and banks value collateral higher at the margin and elevates the opportunity cost of collateral for both (raised Ω^h and Ω^b). As a result, both households and banks hold less collateral against their loans. This implies a backward shift of the collateral supply curve in the banking system. The weaker asset positions of borrowers cause the marginal cost of creating and servicing deposits to go up, thereby implying an elevated banking tax. The $\bar{b}$ shock is quite persistent (resembling a random walk) and its effect are small but weaken only very gradually. As a result, the government debt effect is more important for long-term collateral effects and less relevant for short horizons.

Shock to Banks' Efficiency at Monitoring other Banks

While shocks to F, k and $\bar{b}$ affect the banking system by shifting the collateral supply curve, the shock to $\tilde{F}$ shifts the banking system's demand for collateral. As a result of a negative shock to $\tilde{F}$, the lending banks' efficiency to ensure the credibility of the borrowing banks drops. Therefore interbank lenders value safer asset composition of their borrowers higher at the margin (an upward shift in banks' demand for collateral). Thus, banks bid higher prices for government debt, which motivates households to supply more government debt to the banking system. However, the lower collateral holdings by households increases banks' marginal cost at making loans to households (widened external finance premium). This effect combined with the increased marginal cost of providing payment services elevate the banking tax.

With this background in mind, I now turn to analyze the role of monetary policy in mitigating banking stress.

3.5.2 Monetary Policy Analysis

Under the standard Taylor rule (3.2.27), shocks to banking productivity were shown to induce recession, create deflation and widen interest rate spreads. I will now use the calibrated model to evaluate the performance of the economy when, in addition to reacting to output gap and inflation, the central bank reacts to a measure of banking stress.

Policy Rule Sensitive to the Banking Tax

Ideally, we would like the central bank to directly react to the banking tax (which is unobservable in the model), because it is the channel through which banking shocks impact the aggregate economy. In the model, movements in the banking tax are perfectly aligned with movements in the deposit spread. Therefore, I consider a modified version of the standard Taylor rule specified as

$$R_t^{IB} = (1+\mu_1)\,\Delta p_t + \mu_2\, mc_t - \mu_3\left(R_t^T - R_t^D\right), \tag{3.5.2}$$

where μ_1 and μ_2 are the standard Taylor rule parameters, and $\mu_3 \geqslant 0$ represents sensitivity of the policy rule with respect to variations in the deposit spread. The intuition behind this rule is that the central bank cuts the interbank rate at times of elevated banking tax in addition to its regular response to output gap and inflation. Note that this modification will not matter for the monetary policy's performance with respect to a goods productivity shock, because as the analysis in the previous section showed, the goods productivity shock in the calibrated model has an insignificant effect on the interest rate spreads.

Figure 3.3 displays the response of key endogenous variables of the model in response to a one-standard deviation shock to F, the case in which banking effects were most significant. The monetary authority follows a rule specified as (3.5.2) with different sensitivities to the banking tax ranging from 0 to 1.5.

[Figure 3]

A clear implication of the simulation results illustrated in Figure 3.3 is that the modified monetary policy improves upon the standard Taylor rule by alleviating the recession and deflation caused by banking stress. In particular, when the sensitivity of the interest rate policy to the banking tax equals one, the deflation effect is totally offset. Additionally, the drop in aggregate consumption and employment are halved. The improved economic outcome under the modified rule is attributed to the central bank's commitment to explicitly react to banking stress. A central bank with full credibility to act against banking stress would preemptively stimulate the economy in order to offset the banking tax effect. Moreover, in practice, the central bank requires to reduce the nominal interbank rate much less than the standard Taylor rule. Yet, it can successfully reduce the real shadow rate sufficiently enough to counteract deflation.

In addition to the superior performance of the modified rule relative to the standard Taylor rule for mitigating banking stress, it exhibits the same performance in response to goods productivity shock. The reason is goods productivity shock insignificantly affects the banking tax. Therefore the additional term indeed does not change the behavior of the central bank. In this sense, response to the banking tax sensitivity can be thought of as working like an option in the context of the policy rule.

As Figure 3.3 illustrates, the policy rule that is more sensitive to the banking tax leads to higher banking tax values. The higher sensitivity values are associated with a higher banking tax. This outcome is related to the presence of two counteracting effects. First, the famous *banking accelerator* effect (as in Bernanke, Gertler and Gilchrist (1999)) works though the elevated q-price of capital, which expands collateral and thereby tends to compress the banking tax. The collateral effect is evidenced by the lower TED spread and banks' holding of government debt relative to deposits. Second, the *banking attenuator* effect (introduced by Goodfriend and McCallum (2007)) emerges because of the higher demand for transactions resulting from expanded economic activity. Additionally, the banking attenuator effect works through the elevated wage, which makes employment of monitoring effort by banks more expensive.

The modified Taylor rule robustly responds to other sources of banking stress. Simulation results illustrated in Figure 3.4 reveal that the impact effect of other shocks on deflation can be totally offset when the rule (3.5.2) reacts to the banking tax with a sensitivity around 1.

[Figure 4]

The above discussion illustrates that the central bank can best mitigate the macroeconomic instability caused by banking stress by reacting to the banking tax, which is unobservable. As a result, I consider two alternative observable interest rate spreads in the modified Taylor rule: a) the TED spread and b) the loan-deposit rate spread.

Policy Rule Sensitive to the TED Spread

The TED spread has been commonly used as an indicator of stress in the banking system.[23] It was one of the banking observables that I used to infer the stochastic parameters of banking shocks. In the model, the TED spread represents banks' valuation of collateral services from holding government debt against interbank borrowing. In response to banking stress, the TED spread elevates to indicate higher valuation of collateral by banks at time of banking stress. Therefore, the modified policy rule follows,

$$R_t^{IB} = (1 + \mu_1)\, \Delta p_t + \mu_2\, mc_t - \mu_4 \left(R_t^{IB} - R_t^{B} \right). \tag{3.5.3}$$

Under this rule, the central bank commits to additionally stimulate the economy using its interest rate instrument when the TED spread elevates. Figure 3.5 displays responses of key macroeconomic variables to F and k shocks. The policy sensitivity to the TED spread μ_4, adopts values from 0, 1.75 and 5.

[Figure 5]

Simulation results show that the policy rule sensitive to the TED spread can further stimulate the economy in banking stress in addition to the standard Taylor rule. In particular, when the sensitivity parameter equals 1.75 the central bank can totally offset the deflation caused by the k shock. With this specification, however, the central bank cannot totally offset the deflationary effect of the F shock. Even if the central bank chooses an substantially larger sensitivity (set to 5 in Figure 3.5) in order to better stabilize the macroeconomy in response to the F shock, it will overheat the economy when the k shock takes place.

The policy rule (3.5.3) does not exhibit the desirable performance of the rule (3.5.2), because the TED spread does not perfectly correlate with the banking tax. One reason is that the TED spread is very sensitive to collateral shocks, whereas the banking tax is more sensitive to monitoring efficiency shocks (see Figure 3.2 for a comparison). In other words, the same elevation in the TED spread could differently affect the banking tax depending on the underlying source of banking stress. As discussed in the theoretical section, the monitoring efficiency shock elevates the banking tax more severely because not only it results in elevated opportunity cost of collateral but also it raises the effective factor cost of monitoring (w/F in case of the F shock).

[23] see Giglio, Kelly, and Pruitt (2015), Mankiw (2015), Geithner (2014), The Economic Report of the President (2009) among others

Policy Rule Sensitive to the Loan-Deposit Spread

Alternatively, suppose the central bank reacts to the loan-deposit rate spread in addition to its standard macroeconomic targets. This rule is specified as follows,

$$R_t^{IB} = (1+\mu_1)\,\Delta p_t + \mu_2\, mc_t - \mu_5 \left(R_t^L - R_t^D\right). \tag{3.5.4}$$

Here, the parameter μ_5 represents the sensitivity of the interest rate rule to changes in the loan-deposit spread. Figure 3.6 replicates the same exercise as in Figure 3.5 using the policy rule (3.5.4) instead of (3.5.3). The values of sensitivity parameter, μ_5, are 0, 1 and 2.25.

[Figure 6]

Unlike the previous rule, when the central bank commits to react to the loan-deposit rate spread, it can fully offset the deflation caused by banking stress. When the sensitivity parameter is set to 2.25, the deflation effect of banking stress disappears regardless of the underlying source of stress (as shown for F and k shocks in Figure 3.6).

The reason why the loan-deposit rate spread provides a better account of banking stress compared to the TED spread is that it includes both components of the marginal cost of creating deposits and providing payment services. The only difference between the loan-deposit rate spread and the deposit spread is the discount that households receive on their loan rate in return to posting collateral, $R^T - R^L$. Because the share of collateral in the loan production is fixed α, this difference does not significantly reduce the correlation. Accordingly, the loan-deposit rate spread favorably mimics variations in the banking tax and should therefore be used as the measure of intensity of banking stress by the central bank.

3.6 Conclusion

The primary objective of this paper was to evaluate the macroeconomic significance of fluctuations in the productivity of banking services. Specifically, the model identified four sources that disturb the banking system: (a) banks' efficiency at monitoring households, (b) banks' efficiency at monitoring other banks, (c) the effective collateral value of capital, and (d) the supply of government securities relative to GDP. These sources affect aggregate consumption, employment and inflation by fluctuating the "banking services tax". To quantify the stochastic processes of these sources, the paper developed a methodology that uses macroeconomic and banking observations for the U.S. economy along with the rational expectations solution of the model. Simulations revealed that banking shocks exhibit large standard deviations but low persistence. The large standard deviations mean that a 1% innovation shock has a large impact on the underlying banking shock and the low persistence implies short half-lives of shocks to banking productivity. Therefore, these properties are crucial for a concrete quantitative evaluation of the macroeconomic significance of banking disturbances.

The paper's quantitative exercises provide two important results. First, adverse shocks to the banking system, which reflect financial distress, induce deep recession and deflation. The drop in aggregate consumption is comparable to an adverse goods productivity shock. Moreover, the standard Taylor rule fails to stimulate the economy sufficiently enough to avoid the deflation caused by banking stress. Second, the central bank can stabilize inflation and output resulting from banking stress by reacting to variations in the banking tax in addition to inflation and output gap. However, the banking tax is not observable. Two observable alternatives were studied: the TED spread, and the loan-deposit rate spread. The TED spread is less preferred because it is more sensitive to collateral shocks than the banking tax, while the loan-deposit rate spread is a good proxy for the banking tax. Therefore, the central bank should follow a Taylor rule that is sensitive to the loan-deposit rate spread to best mitigate the impact of banking stress.

This work focused on the fluctuations in the productivity of the banking system to supply payment services. Future studies should consider the demand side by modeling households' demand for payment services and explore how fluctuations in the demand for transaction-facilitating deposits translate into variation in the banking tax. Future studies should also investigate if and to what extent corporate demand for funds for investment purposes could lead to variations in the banking tax.

Appendices

Appendix C

C.1 First Order Conditions

The representative household's problem is to maximize its expected lifetime utility,

$$E_0 \sum_{t=0}^{\infty} \beta^t [\phi \log(c_t) + (1-\phi) \log(1-n_t^s)], \tag{C.1.1}$$

subject to the deposit-in-advance constraint

$$V \frac{D_t^d}{P_t^A} \geqslant c_t, \tag{C.1.2}$$

the flow of funds constraint

$$\frac{D_{t-1}^d}{P_t^A}(1+R_{t-1}^D) + \frac{B_t^h}{P_t^A} + w_t n_t^s + \Pi_t^f + \Pi_t^b \geqslant \frac{D_t^d}{P_t^A} + \frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + c_t + \tau_t, \tag{C.1.3}$$

the goods production and sales constraint

$$K_t^\eta (A_t n_t)^{1-\eta} \geqslant c_t^A \left(\frac{P_t}{P_t^A}\right)^{-\theta}, \tag{C.1.4}$$

the deposit creation and servicing constraints

$$\left(\frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + k_t q_t K_{t+1}\right)^\alpha (F_t m_t)^{1-\alpha} + \frac{B_{t+1}^b}{P_t^A(1+R_t^B)} \geqslant \frac{D_t^s}{P_t^A}, \tag{C.1.5}$$

$$\left(\frac{B_{t+1}^b}{P_t^A(1+R_t^B)}\right)^{\tilde{\alpha}} (\tilde{F}_t \tilde{m}_t)^{1-\tilde{\alpha}} \geqslant \ell \frac{D_t^s}{P_t^A}, \tag{C.1.6}$$

taking price variables and interest rates as given. In the flow of funds constraint,

$$\Pi_t^f = c_t^A \left(\frac{P_t}{P_t^A}\right)^{-(\theta-1)} + q_t(1-\delta)K_t - q_t K_{t+1} - w_t n_t, \tag{C.1.7}$$

$$\Pi_t^b = \frac{D_t^s}{P_t^A} + \frac{B_t^b}{P_{t-1}^A} - \frac{D_{t-1}^s}{P_{t-1}^A}(1+R_{t-1}^D) - \frac{B_{t+1}^b}{P_t^A(1+R_t^B)} - w_t(m_t + \tilde{m}_t). \tag{C.1.8}$$

The Lagrangian of the representative household's problem is therefore given by,

$$\begin{aligned}
\mathscr{L}_0 =& E_0 \sum_{t=0}^{\infty} \beta^t \Big[\phi \log(c_t) + (1-\phi) \log(1-n_t^s)\Big] \\
&+\nu_t \left[\frac{D_t^d}{P_t^A} - \frac{1}{V} c_t\right] \\
&+\lambda_t \left[\frac{D_t^s - D_t^d}{P_t^A} - \frac{D_{t-1}^s - D_{t-1}^d}{P_t^A}(1+R_{t-1}^D) + q_t\left((1-\delta)K_t - K_{t+1}\right) + c_t^A \left(\frac{P_t}{P_t^A}\right)^{-(\theta-1)}\right. \\
&\qquad \left. + \frac{B_{t+1}^h + B_{t+1}^b}{P_t^A(1+R_t^B)} - \frac{B_t^h + B_t^b}{P_t^A} + w_t\big[n_t^s - (n_t + m_t + \tilde{m}_t)\big] - \tau_t - c_t\right] \\
&+\xi_t \left[K_t^\eta (A_t n_t)^{1-\eta} - c_t^A \left(\frac{P_t}{P_t^A}\right)^{-\theta}\right] \\
&+\psi_t \left[\left(\frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + k_t q_t K_{t+1}\right)^{\alpha} (F_t m_t)^{1-\alpha} + \frac{B_{t+1}^b}{P_t^A(1+R_t^B)} - \frac{D_t^s}{P_t^A}\right] \\
&+\tilde{\psi}_t \left[\left(\frac{B_{t+1}^b}{P_t^A(1+R_t^B)}\right)^{\tilde{\alpha}} \left(\tilde{F}_t \tilde{m}_t\right)^{1-\tilde{\alpha}} - \ell \frac{D_t^s}{P_t^A}\right].
\end{aligned} \tag{C.1.9}$$

The first order conditions are accordingly given by,

$$\partial c_t: \quad \frac{\phi}{c_t} - \frac{1}{V}\nu_t - \lambda_t = 0 \tag{C.1.10}$$

$$\partial D_t^d: \quad \nu_t - \lambda_t + \beta E_t\left[\lambda_{t+1}\frac{1+R_t^D}{1+\pi_{t+1}}\right] = 0 \tag{C.1.11}$$

$$\partial D_t^s: \quad \lambda_t - \psi_t - \ell\tilde{\psi}_t - \beta E_t\left[\lambda_{t+1}\frac{1+R_t^D}{1+\pi_{t+1}}\right] = 0 \tag{C.1.12}$$

$$\partial n_t^s: \quad -\frac{1-\phi}{1-n_t^s-m_t^s-\tilde{m}_t^s} + w_t\lambda_t = 0 \tag{C.1.13}$$

$$\partial n_t: \quad -w_t\lambda_t + \xi_t(1-\eta)A_t\left(\frac{K_t}{A_t n_t}\right)^{\eta} = 0 \tag{C.1.14}$$

$$\partial m_t: \quad -w_t\lambda_t + \psi_t(1-\alpha)F_t\left[\frac{\frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + k_t q_t K_{t+1}}{F_t m_t}\right]^{\alpha} = 0 \tag{C.1.15}$$

$$\partial \tilde{m}_t: \quad -w_t\lambda_t + \tilde{\psi}_t(1-\tilde{\alpha})\tilde{F}_t\left[\frac{\frac{B_{t+1}^b}{P_t^A(1+R_t^B)}}{\tilde{F}_t\tilde{m}_t}\right]^{1-\tilde{\alpha}} = 0 \tag{C.1.16}$$

$$\partial P_t: \quad -\lambda_t\left(\frac{c_t^A}{P_t^A}\right)(\theta-1)\left(\frac{P_t}{P_t^A}\right)^{-\theta} + \xi_t\left(\frac{c_t^A}{P_t^A}\right)\theta\left(\frac{P_t}{P_t^A}\right)^{-\theta-1} = 0 \tag{C.1.17}$$

$$\partial K_{t+1}: \quad -\lambda_t q_t + \psi_t k_t q_t \Omega_t^h + \beta E_t\left[\lambda_{t+1}q_{t+1}(1-\delta) + \eta\,\xi_{t+1}\left(\frac{A_{t+1}n_{t+1}}{K_{t+1}}\right)^{1-\eta}\right] = 0 \tag{C.1.18}$$

$$\partial B_{t+1}^h: \quad -\lambda_t + \psi_t\Omega_t^h + E_t\left[\frac{\beta\lambda_{t+1}}{1+\pi_{t+1}}\right]\left(1+R_t^B\right) = 0 \tag{C.1.19}$$

$$\partial B_{t+1}^b: \quad -\lambda_t + \psi_t + \tilde{\psi}_t\Omega_t^b + E_t\left[\frac{\beta\lambda_{t+1}}{1+\pi_{t+1}}\right]\left(1+R_t^B\right) = 0 \tag{C.1.20}$$

where, by definition $\Omega_t^h = \alpha\left[\frac{F_t m_t}{\frac{B_{t+1}^h}{P_t^A(1+R_t^B)} + k_t q_t K_{t+1}}\right]^{1-\alpha}$, and $\Omega_t^b = \tilde{\alpha}\left[\frac{\tilde{F}_t\tilde{m}_t}{\frac{B_{t+1}^b}{P_t^A(1+R_t^B)}}\right]^{1-\tilde{\alpha}}$.

C.2 Dynamic Equations

$$E_t\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{1+\pi_{t+1}}\right](1+R_t^T)=1 \tag{C.2.1}$$

$$\frac{\phi}{c_t\lambda_t}=1+\frac{1}{V}\left(\frac{R_t^T-R_t^D}{1+R_t^T}\right) \tag{C.2.2}$$

$$\frac{1-\phi}{1-n_t-m_t-\tilde{m}_t}=w_t\lambda_t \tag{C.2.3}$$

$$1=k_t\Omega_t^h\left(\frac{R_t^T-R_t^{IB,T}}{1+R_t^T}\right)+\frac{1}{1+R_t^T}E_t\left((1-\delta)\frac{q_{t+1}}{q_t}+\frac{\eta\cdot mc_{t+1}}{q_t}\left(\frac{A_{t+1}n_{t+1}}{K}\right)^{1-\eta}\right) \tag{C.2.4}$$

$$R_t^T-R_t^B=\Omega_t^h\left(R_t^T-R_t^{IB,T}\right) \tag{C.2.5}$$

$$R_t^{IB,T}-R_t^B=\frac{\Omega_t^b}{\ell}\left(R_t^{IB,T}-R_t^D\right) \tag{C.2.6}$$

$$w_tm_t=\left(\frac{R_t^T-R_t^{IB,T}}{1+R_t^T}\right)(1-\alpha)\frac{L_t^h}{P_t} \tag{C.2.7}$$

$$w_t\tilde{m}_t=\left(\frac{R_t^{IB,T}-R_t^D}{1+R_t^T}\right)(1-\tilde{\alpha})\frac{L_t^b}{P_t} \tag{C.2.8}$$

$$K^\eta(A_tn_t)^{1-\eta}=c_t+\delta Kq_t \tag{C.2.9}$$

$$\frac{B_{t+1}^h}{P_t(1+R_t^B)}+\frac{B_{t+1}^b}{P_t(1+R_t^B)}=\bar{b}_t\,c_t \tag{C.2.10}$$

$$V\,\frac{D_t}{P_t}=c_t \tag{C.2.11}$$

$$L_t^h+\frac{B_{t+1}^h}{1+R_t^B}=D_t \tag{C.2.12}$$

$$\frac{L_t^h}{P_t}=\left(\frac{B_{t+1}^h}{P_t(1+R_t^B)}+k_tq_tK\right)^\alpha(F_tm_t)^{1-\alpha} \tag{C.2.13}$$

$$L_t^b=\ell\,D_t \tag{C.2.14}$$

$$\frac{L_t^b}{P_t}=\left(\frac{B_{t+1}^b}{P_t(1+R_t^B)}\right)^{\tilde{\alpha}}\left(\tilde{F}_t\tilde{m}_t\right)^{1-\tilde{\alpha}} \tag{C.2.15}$$

$$R_t^T-R_t^L=\alpha\left(R_t^T-R_t^{IB,T}\right) \tag{C.2.16}$$

$$R_t^{IB,T}-R_t^{IB}=\frac{\tilde{\alpha}}{\ell}\left(R_t^{IB,T}-R_t^D\right), \tag{C.2.17}$$

which together with the interest rate policy solve for c_t, D_t, R_t^B, n_t, w_t, q_t, B_{t+1}^h, B_{t+1}^b, L_t^h, L_t^b, m_t, $\tilde{m}_t$, λ_t, R_t^T, R_t^L, $R_t^{IB,T}$, R_t^{IB} and R_t^D, given evolutions of shocks A_t, F_t, $\tilde{F}_t$, and $\bar{b}_t$, and define $mc_t=\frac{w_tn_t}{(1-\eta)(c_t+\delta Kq_t)}$.

C.3 Log-linearized Dynamic Equations

$$R_t^T = -E_t\hat{\lambda}_{t+1} + \hat{\lambda}_t + E_t\Delta p_{t+1} \tag{C.3.1}$$

$$\frac{\phi}{c\lambda}\left(-\hat{c}_t - \hat{\lambda}_t\right) = \frac{1}{V}\frac{1+R^D}{1+R^T}\left(R_t^T - R_t^D\right) \tag{C.3.2}$$

$$\hat{\lambda}_t + \hat{w}_t = \frac{n}{1-n-m-\tilde{m}}\hat{n}_t + \frac{m}{1-n-m-\tilde{m}}\hat{m}_t + \frac{\tilde{m}}{1-n-m-\tilde{m}}\hat{\tilde{m}}_t \tag{C.3.3}$$

$$\hat{mc}_t = \hat{n}_t + \hat{w}_t - \hat{c}_t \tag{C.3.4}$$

$$0 = k\Omega^h\left(R^T - R^{IB,T}\right)\left(\frac{R_t^T - R_t^{IB,T}}{R^T - R^{IB,T}} - R_t^T + \hat{\Omega}_t^h + \hat{k}_t\right) - \frac{1+R^K}{1+R^T}\left(R_t^T - E_t R_{t,t+1}^K\right) \tag{C.3.5}$$

$$\frac{R_t^T - R_t^B}{R^T - R^B} = \frac{R_t^T - R_t^{IB,T}}{R^T - R^{IB,T}} + \hat{\Omega}_t^h \tag{C.3.6}$$

$$\frac{R_t^{IB,T} - R_t^B}{R^{IB,T} - R^B} = \frac{R_t^{IB,T} - R_t^D}{R^{IB,T} - R^D} + \hat{\Omega}_t^b \tag{C.3.7}$$

$$\hat{w}_t + \hat{m}_t = \frac{R_t^T - R_t^{IB,T}}{R^T - R^{IB,T}} - R_t^T + \hat{L}_t^h - \hat{P}_t \tag{C.3.8}$$

$$\hat{w}_t + \hat{\tilde{m}}_t = \frac{R_t^{IB,T} - R_t^D}{R^{IB,T} - R^D} - R_t^T + \hat{D}_t - \hat{P}_t \tag{C.3.9}$$

$$\hat{c}_t = \left(1 + \frac{\delta K}{c}\right)(1-\eta)(\hat{n}_t + \hat{A}_t) - \frac{\delta K}{c}\hat{q}_t \tag{C.3.10}$$

$$B^h\ \hat{B}_{t+1}^h + B^b\ \hat{B}_{t+1}^b = \bar{b}\ c\left(1+R^B\right)\left(\hat{\bar{b}}_t + \hat{c}_t\right) \tag{C.3.11}$$

$$\hat{c}_t = \hat{D}_t - \hat{P}_t \tag{C.3.12}$$

$$L^h\hat{L}_t^h + \frac{B^b}{1+R^B}\left(\hat{B}_{t+1}^h - R_t^B\right) = D\hat{D}_t \tag{C.3.13}$$

$$\tilde{\alpha}\left(\hat{B}_{t+1}^b - R_t^B - \hat{P}_t\right) + (1-\tilde{\alpha})\left(\hat{\tilde{F}}_t + \hat{\tilde{m}}_t\right) = \hat{D}_t - \hat{P}_t \tag{C.3.14}$$

$$R_t^T - R_t^L = \alpha\left(R_t^T - R_t^{IB,T}\right) \tag{C.3.15}$$

$$R_t^{IB,T} - R_t^{IB} = \frac{\tilde{\alpha}}{\ell}\left(R_t^{IB,T} - R_t^D\right) \tag{C.3.16}$$

$$\hat{L}_t^h - \hat{P}_t = \alpha\left(\frac{b^h}{b^h + kK}\left(\hat{B}_{t+1}^h - R_t^B - \hat{P}_t\right) + \frac{kK}{b^h + kK}\hat{q}_t\right) + (1-\alpha)\left(\hat{F}_t + \hat{m}_t\right) \tag{C.3.17}$$

$$\Delta p_t = \beta E_t \Delta p_{t+1} + \kappa\ mc_t \tag{C.3.18}$$

$$R_t^{IB} = (1+\mu_1)\Delta p_t + \mu_2\ \hat{mc}_t \tag{C.3.19}$$

$$\Delta P_{t+1} = \hat{P}_{t+1} - \hat{P}_t \tag{C.3.20}$$

Table 3.1: Parameter values under the baseline calibration
(excluding parameters of stochastic processes)

Standard Macroeconomic Parameters

Parameter	Value	Description
β	0.99	Households' discount factor
γ	0.005	Economy's (technological) growth rate
ϕ	0.4	Utility weight of consumption relative to leisure
η	0.36	Share of capital in goods production
θ	11	Price elasticity of aggregate demand for goods
δ	0.025	Depreciation rate of capital stock

Aggregate Money and Government Debt Measures

Parameter	Value	Description
V	0.48	Velocity of broad money
$\bar{b}$	1.06	Supply of government debt relative to GDP

Banking-specific Parameters

Parameter	Value	Description
α	0.55	Share of collateral in loans to households
F	1150	Banks' efficiency at monitoring households
k	0.01	Collateral productivity of capital relative to government debt
$\tilde{\alpha}$	0.65	Share of government debt in interbank loans
$\tilde{F}$	11500	Banks' efficiency at monitoring other banks
ℓ	0.45	Interbank loan per dollar of deposits

which solve for c, w, q, λ, n, Δp, mc, D, L^h, b^b, b^h, m, $\tilde{m}$, R^T, R^L, $R^{IB,T}$, R^{IB}, R^B, R^D.

$$
\begin{aligned}
R^K_{t,t+1} &= \frac{1-\delta}{1+R^K}\left(\hat{q}_{t+1}-\hat{q}_t\right) + \frac{\eta\cdot mc}{1+R^K}\left(\frac{n}{K}\right)^{1-\eta}\left(\hat{mc}_{t+1}+(1-\eta)(a1_{t+1}+n_{t+1})-\hat{q}_t\right) \\
\hat{\Omega}^h_t &= \hat{L}^h_t - \hat{P}_t - \left(\frac{b^h}{b^h+kK}\hat{b}^h_{t+1} + \frac{kK}{b^h+kK}\left(\hat{q}_t+\hat{k}_t\right)\right) \\
\hat{\Omega}^b_t &= \hat{D}_t + R^B_t - \hat{B}^b_{t+1}.
\end{aligned}
$$

Table 3.2: Comparison of average values of observables over the sample to the model-implied endogenous variables

Variable	Value	Model output	Description
$R^{IB} - R^{B}$	0.57%	0.51%	The TED spread
B^{b}/D	21.2%	21.77%	Banks' holding of government debt relative to deposits
R^{B}	0.94%	1.03%	The real three-month T-bill rate
$R^{L} - R^{IB}$	2.0%	2.3%	The external finance premium
R^{D}	1.28%	1.26%	Average deposit rate on all deposits
$(m + \tilde{m})/n^{s}$	1.4%	1.0%	Share of banking employment in total employment

Table 3.3: The steady-state solution of the model with benchmark calibration compared with cost-free banking

	Steady-state with costly banking					
Macroeconomic variables:	c	w	K	λ	n	mc
	0.8204	1.8972	8.9328	0.4768	0.3334	0.9091
Interest rates (p.a.):	R^{T}	R^{L}	$R^{IB,T}$	R^{IB}	R^{B}	$R^{D'}$
	0.0606	0.0384	0.0202	0.0154	0.0103	0.0126
Banking variables:	D	B^{b}/D	m	$\tilde{m}$	Ω^{h}	Ω^{b}
	1.7092	0.2177	0.0031	0.0003	1.2451	1.3435
	Steady-state with cost-free banking					
Macroeconomic variables:	c	w	K	λ	n	mc
	0.8342	1.8938	9.0458	0.4795	0.3392	0.9091

Table 3.4: Calibrated shock processes in the model.
Note: Half-life values are reported in quarters.

	ρ	**half-life**	**σ(shock)**	**σ(innovation)**	**Description**
A	0.938	11	0.036	0.012	Goods productivity
$\bar{b}$	0.967	21	0.130	0.023	Supply of government debt relative to GDP
F	0.937	11	0.848	0.299	Banks' efficiency at monitoring households
$\tilde{F}$	0.801	3	0.683	0.411	Banks' efficiency at monitoring other banks
k	0.896	6	1.644	0.734	Effective collateral value of capital

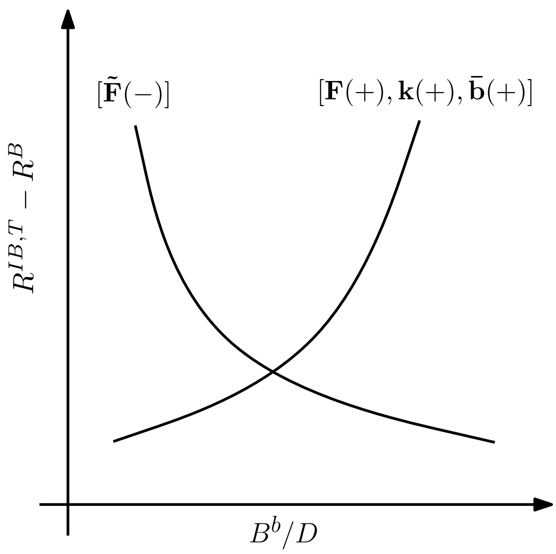


Figure 3.1: Supply and Demand of Government Bonds in Banking .
Note: Sources of disturbances in the banking system that shift each curve are displayed in brackets.

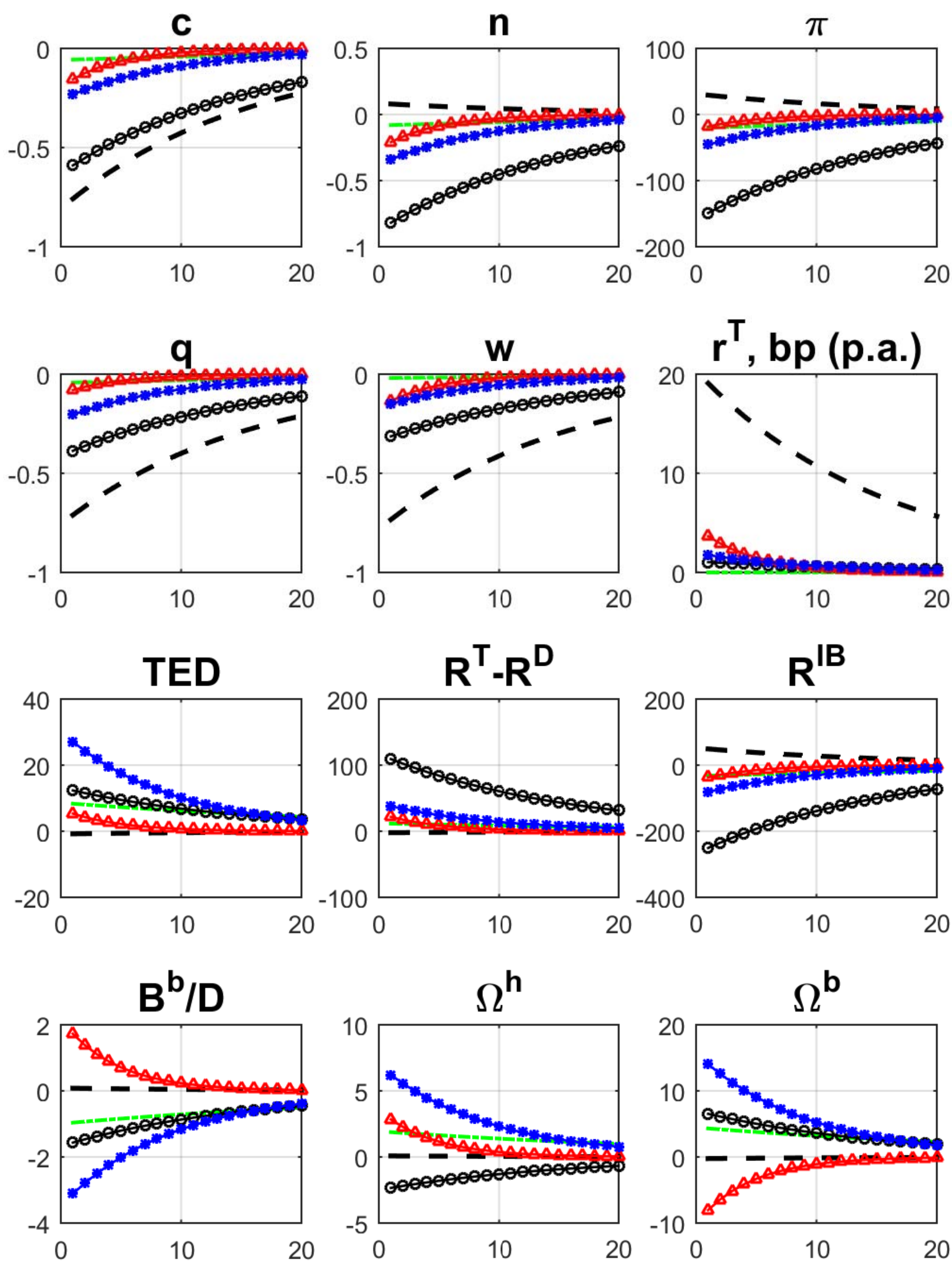


Figure 3.2: Responses to negative shocks to A_t (thick dashed line), F_t (circle line), $\tilde{F}_t$ (triangle line) and k_t (star line).

Note: Sizes of all shocks are one standard deviation and persistence levels reported in Table 3.4. Numbers represent quarterly fractional deviations from steady state for all variables, except inflation, interest rates and rate spreads, which are represented in p.a. basis point changes, and B^b/D, which is expressed in percentage point changes.

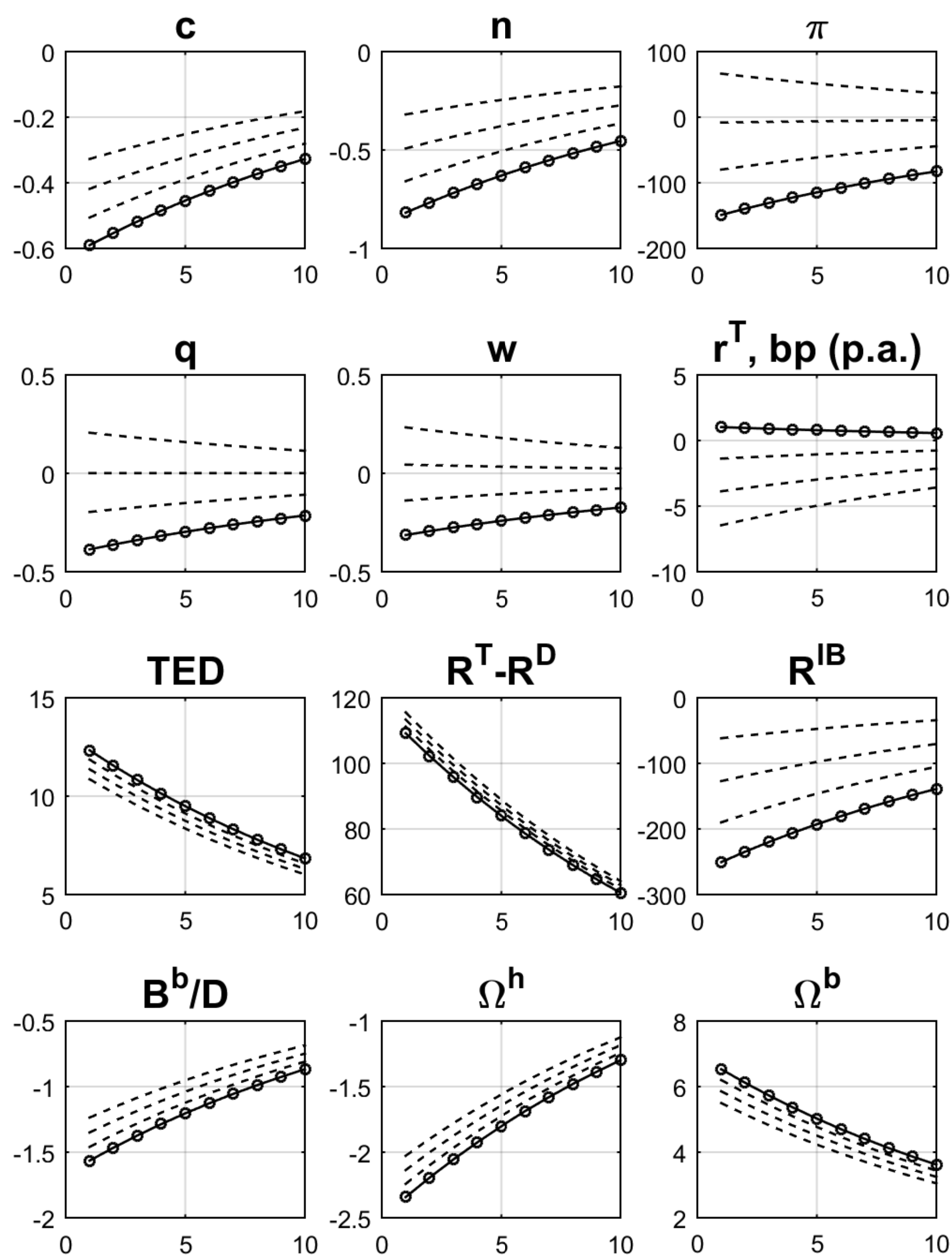


Figure 3.3: Responses to a one-standard deviation negative shock to F_t with monetary policy specified as (3.5.2).

Note: The circle black lines represent responses of the economy under a standard Taylor rule ($\mu_3 = 0$). Dashed lines represent responses with $\mu_3 = 0.5, 1$ and 1.5.

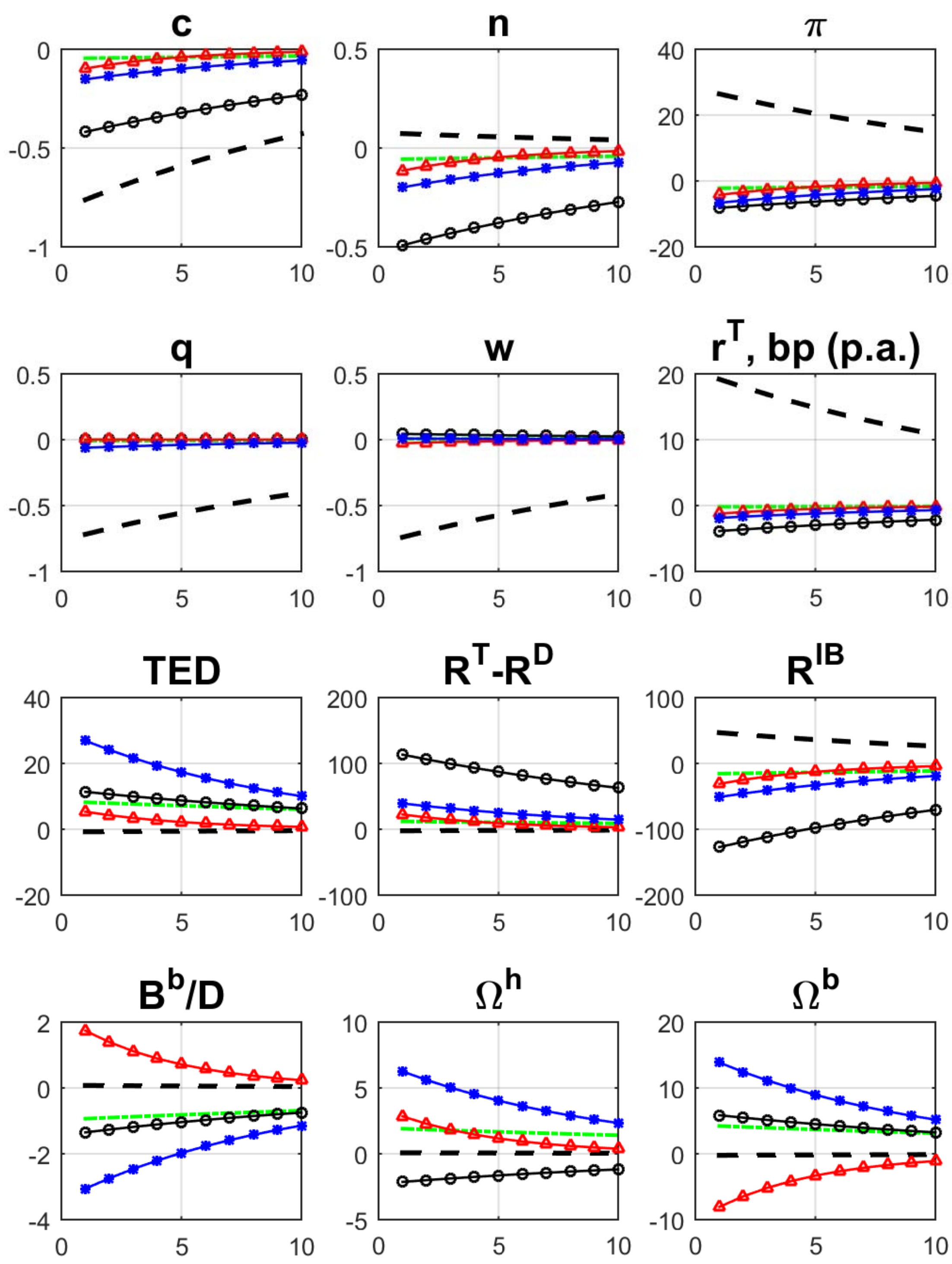


Figure 3.4: Responses to negative shocks to A_t (thick dashed line), F_t (circle line), $\tilde{F}_t$ (triangle line) and k_t (star line) under the rule (3.5.2) with $\mu_3 = 1$.

Note: Sizes of all shocks are one standard deviation and persistence levels reported in Table 3.4. Numbers represent quarterly fractional deviations from steady state for all variables, except inflation, interest rates and rate spreads, which are represented in p.a. basis point changes, and B^b/D, which is expressed in percentage point changes.

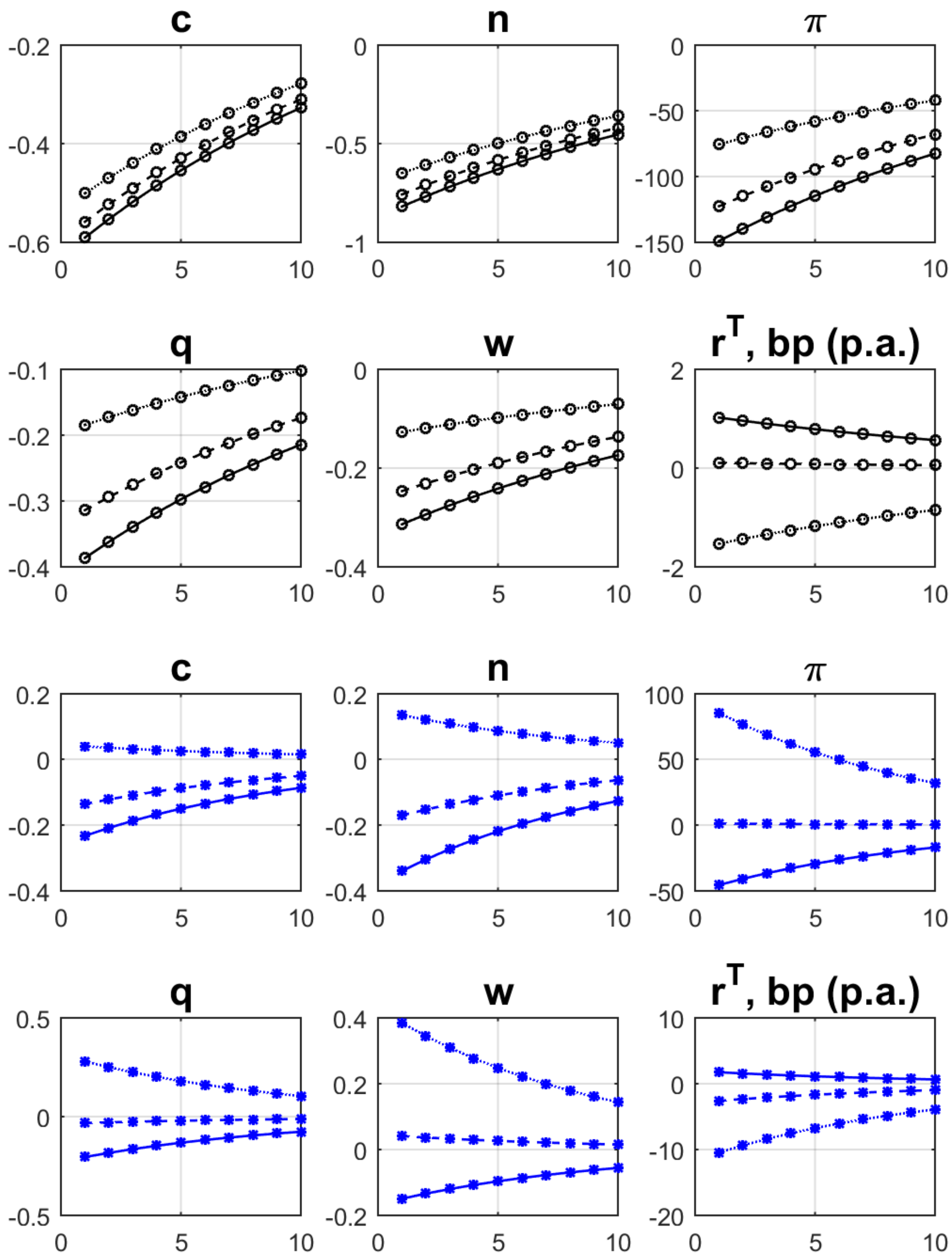


Figure 3.5: Responses to one-standard deviation negative shocks to F_t (circle, top panel) and k_t (star, bottom panel) under the rule (3.5.3) with $\mu_4 = 0$ (solid line), $\mu_4 = 1.75$ (dashed line) and $\mu_4 = 5$ (dotted line).

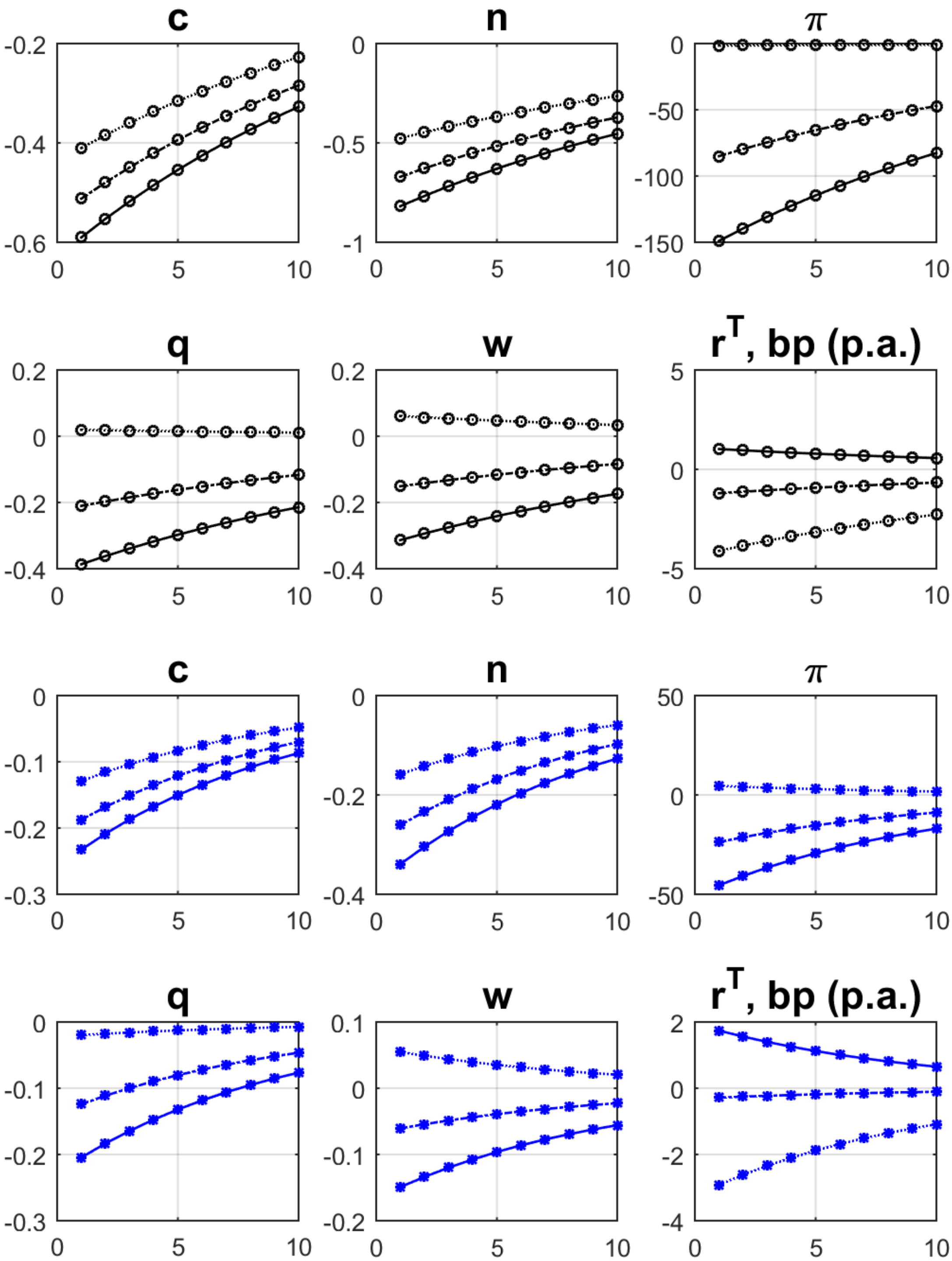


Figure 3.6: Responses to one-standard deviation negative shocks to F_t (circle, top panel) and k_t (star, bottom panel) under the rule (3.5.3) with $\mu_5 = 0$ (solid line), $\mu_5 = 1$ (dashed line) and $\mu_5 = 2.25$ (dotted line).

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