The Role of Bank Capital in the Propagation of Shocks *

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Abstract

Recent events in financial markets have underlined the importance of analyzing the link between the financial health of banks and real economic activity. We develop a dynamic stochastic general equilibrium model with a banking sector in which bank capital emerges endogenously to solve an asymmetric information problem between banks and their creditors. The capital position of a bank thus affects its ability to attract loanable funds and, as a result, bank capital influences the business cycle through a bank capital channel of transmission. The model is used to conduct quantitative experiments on the economy's responses to technology and monetary policy shocks, as well as to financial shocks originating within the banking sector. We find that the bank capital channel amplifies and propagates the effects of shocks on output, investment and inflation. Further, we show that financial shocks causing exogenous declines in bank capital create sizeable declines in output and investment. These results suggest that accounting for the role of bank capital is important when building models for business cycle and monetary policy analysis.

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1 Introduction

The balance sheets of banks worldwide have recently come under stress, as significant asset writedowns led to sizeable reductions in bank capital. These events have generated a 'credit crunch', in which banks cut back on lending and firms found it harder to obtain external financing. Concerns have been raised that these adverse financial conditions will continue to undermine economic activity, much like shortages in bank capital slowed down recovery from the 1990-91 recession (Bernanke and Lown, 1991). This has sustained interest for quantitative business cycle models that can analyze the interactions between bank capital dynamics and the business cycle.

However, the balance sheets of banks and their capital are absent from most of the recent contributions in developing dynamic stochastic general equilibrium (DSGE) models with financial frictions (Bernanke et al., 1999; Christiano et al., 2008; Iacoviello, 2005; Kiyotaki and Moore, 1997). As a result, these models imply that lending by banks is unaffected by their capital position. This constitutes a limitation of current quantitative models of financial frictions and is in contradiction with an important body of evidence suggesting that bank capital affects bank lending and economic activity.[1]

Our paper develops a DSGE model with a banking sector in which bank capital emerges endogenously to solve an asymmetric information problem between bankers and their creditors. The capital position of a bank thus affects its ability to attract loanable funds and, as a result, bank capital influences the business cycle through a *bank capital channel* of transmission. We incorporate this channel of transmission in a medium-scale version of the New Keynesian paradigm, in the spirit of Christiano et al. (2005) and Smets and Wouters (2007). Our paper thus enables this type of modeling, widely used for monetary policy analysis, to account for the role of bank capital in the propagation of shocks.

In the model, investors lack the ability to monitor the economy's entrepreneurs and thus do not lend directly. Instead, they deposit funds at banks, to whom they delegate the task of monitoring entrepreneurs. However, banks may not monitor adequately, since doing so is costly and not publicly observable, and any resulting risk in their loan portfolio would be mostly borne by investors. This moral hazard problem is mitigated when banks invest their own net worth (their capital) in entrepreneur projects, so that they also have a lot to lose from loan default.[2] In our model, therefore, the capital position of banks affects their ability to attract loanable funds, finance entrepreneurs and sustain economic

[1] For example, Peek and Rosengren (1997, 2000) show that decreases in the capitalization of Japanese banks in the late 1980s had adverse effects on economic activity in regions where these banks had a major presence. Moreover, bank-level data (Kishan and Opiela, 2000; Van den Heuvel, 2007) indicate that poorly capitalized banks reduce lending more significantly following monetary policy contractions. Finally, Van den Heuvel (2002) shows that U.S. states whose banking systems are less capitalized are more sensitive to monetary policy shocks.

[2] Throughout, we use the terms 'bank net worth', 'bank capital', or 'bank equity' interchangeably.

activity. A second source of moral hazard, affecting the relationship between banks and entrepreneurs, is present in the model and implies that the dynamics in entrepreneurial net worth also influence the economy. This double moral hazard framework, introduced in Holmstrom and Tirole (1997) and Chen (2001), thus allows for a rich set of interactions between bank capital, entrepreneurial net worth, and economic activity.

The bank capital channel propagates shocks as follows. A negative technology shock, for example, reduces the profitability of bank lending, making it harder for banks to attract loanable funds. Banks must therefore finance a larger share of entrepreneur projects from their own net worth (their capital), which requires an increase in their capital-to-loan (or capital adequacy) ratio. Since bank capital is mostly comprised of retained earnings, it cannot adjust immediately and bank lending falls, along with aggregate investment. These initial declines propagate the shock to future periods, because lower investment depresses bank earnings, which translates into lower bank capital in future periods and thus further decreases in aggregate investment.[3]

The main findings of our paper are as follows. First, impulse response functions show that the presence of an active bank capital channel amplifies and propagates the effects of shocks on output, investment and inflation. The strength of this effect depends on the nature of the shock: it is stronger for technology shocks (i.e. supply shocks) and more limited for monetary policy shocks (i.e. demand shocks). We also show that when the bank capital channel is active, an economy with more bank capital is better able to absorb negative shocks than an economy with less bank capital. Since our model contains several features in addition to financial frictions, such as habit formation in household consumption, price and wage rigidities, and variable capital utilization in production, these results indicate that accounting for the role of bank capital is important when building medium-scale models for business cycle and monetary policy analysis.

Our second finding is that a financial shock, which causes exogenous decreases in bank capital, leads to sizeable declines in bank lending, investment and output. This shows that banks can not only amplify and propagate shocks, but can also be an independent source of shocks with important consequences on real economic activity.

Our third finding is that the cyclical properties of the model are broadly similar to those in the data over key aspects. More specifically, the influence of the bank capital channel manifests itself in counter-cyclical patterns in the capital adequacy ratios, and we document that these patterns match those in the data, providing an important validation of our framework.

An independent work that is closely related to our paper is from Aikman and Paustian (2006), who also use the double moral hazard framework of Holmstrom and Tirole (1997)

[3]The dynamics of entrepreneurial net worth reinforce the bank capital channel, by creating the 'financial accelerator' discussed in the literature (Carlstrom and Fuerst, 1997; Bernanke et al., 1999).

and Chen (2001). Our paper and the one by Aikman and Paustian are different, however, and make complementary contributions. We differ in terms of modeling and also in terms of the question. On the modeling side, the papers differ in two important aspects. First, we introduce the financial frictions (i.e. the double moral hazard problem) in the sector producing capital goods, which can increase the impact of the frictions on the economy because it makes them interact with intertemporal savings decisions (Carlstrom and Fuerst, 1998). Second, we combine the double moral hazard problem with a medium-scale model, consistent with recent literature on New Keynesian models (Christiano et al., 2005), to verify that it remains an important channel of propagation even in larger models. Our paper and the one by Aikman and Paustian are also different in terms of the question. As discussed above, our findings single out the specific role played by the bank capital channel in the transmission of shocks, while Aikman and Paustian's objective is to characterize optimal monetary policy in a New Keynesian model with bank capital.

Other related work includes Van den Heuvel (2008), in which the dynamics of bank capital also influence bank lending and economic activity, but where bank capital is motivated by regulatory requirements; Meh and Moran (2004), in which monetary non-neutralities arise from limited participation rather than nominal rigidities, and Markovic (2006), in which financial frictions arise within a costly state verification framework. Finally, recent papers by Goodfriend and McCallum (2007), Christiano et al. (2008) and Cúrdia and Woodford (2008) analyze banking in dynamic models but do not emphasize bank capital.

The remainder of this paper is organized as follows. Section 2 describes the model and Section 3 discusses the model's calibration. Section 4 presents our main findings and Section 5 provides a sensitivity analysis. Section 6 concludes.

2 The Model

2.1 The environment

This section describes the structure of the model and the optimization problem of the economy's agents. Time is discrete, and one model period represents a quarter. There are three classes of economic agents in the model: households, entrepreneurs, and bankers, whose population masses are η^h, η^e and $\eta^b = 1 - \eta^h - \eta^e$, respectively. In addition there are firms producing intermediate and final goods, as well as a monetary authority.

There are three goods in the economy. First, intermediate goods are produced by monopolistically competitive firms facing nominal rigidities. Then, final goods are assembled by competitive firms using the intermediate goods. Third, capital goods are produced by entrepreneurs, with a technology that uses final goods as inputs and is affected by idiosyncratic uncertainty.

Two moral hazard problems affect the production of capital goods. First, entrepreneurs

can influence their technology's probability of success and may choose projects with a low probability of success, to enjoy private benefits. Monitoring entrepreneurs helps reduce this problem, but does not eliminate it completely. As a result, banks require entrepreneurs to invest their own net worth when lending to them. The second moral hazard problem occurs between banks and investors, their own source of funds. Investors lack the ability to monitor entrepreneurs so they deposit funds at banks and delegate the task of monitoring entrepreneurs to their bank. However, banks may not properly monitor, because this activity is private and costly, and any resulting risk in their loan portfolio would be mostly borne by investors. As a result, investors require banks to invest their own net worth (their capital) in entrepreneurs' projects. This double moral hazard framework implies that over the business cycle, the dynamics of bank capital affects how much banks can lend, and the dynamics of entrepreneurial net worth affects how much entrepreneurs can borrow. A key contribution of our analysis is to investigate quantitatively the role of the bank capital channel in the propagation of shocks.

2.2 Final good production

Competitive firms produce the final good by combining a continuum of intermediate goods indexed by $j \in (0,1)$ using the standard Dixit-Stiglitz aggregator:

$$Y_t = \left(\int_0^1 {y_{jt}}^{\frac{\xi_p - 1}{\xi_p}} \mathrm{d}j \right)^{\frac{\xi_p}{\xi_p - 1}}, \qquad \xi_p > 1, \tag{1}$$

where y_{jt} denotes the time t input of the intermediate good j, and ξ_p is the constant elasticity of substitution between intermediate goods.

Profit maximization leads to the following first-order condition for the choice of y_{jt}:

$$y_{jt} = \left(\frac{p_{jt}}{P_t} \right)^{-\xi_p} Y_t, \tag{2}$$

which expresses the demand for good j as a function of its relative price p_{jt}/P_t and of overall production Y_t. Imposing the zero-profit condition leads to the usual definition of the final-good price index P_t:

$$P_t = \left(\int_0^1 {p_{jt}}^{1-\xi_p} \mathrm{d}j \right)^{\frac{1}{1-\xi_p}}. \tag{3}$$

2.3 Intermediate good production

Firms producing intermediate goods operate under monopolistic competition and nominal rigidities in price setting. The firm producing good j operates the technology

$$y_{jt} = \begin{cases} z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} h_{jt}^{e\ \theta_e} h_{jt}^{b\ \theta_b} - \Theta & \text{if } z_t k_{jt}^{\theta_k} h_{jt}^{\theta_h} h_{jt}^{e\ \theta_e} h_{jt}^{b\ \theta_b} \geq \Theta \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

where k_{jt} and h_{jt} are the amount of capital and labor services, respectively, used by firm j at time t. In addition, h_{jt}^e and h_{jt}^b represent labor services from entrepreneurs and bankers.[4] Finally, $\Theta > 0$ represents the fixed cost of production and z_t is an aggregate technology shock that follows the autoregressive process

$$\log z_t = \rho_z \log z_{t-1} + \varepsilon_{zt}, \tag{5}$$

where $\rho_z \in (0, 1)$ and ε_{zt} is *i.i.d.* with mean 0 and standard deviation σ_z.

Minimizing production costs for a given demand solves the problem

$$\min_{\{k_{jt}, h_{jt}, h_{jt}^e, h_{jt}^b\}} r_t k_{jt} + w_t h_{jt} + w_t^e h_{jt}^e + w_t^b h_{jt}^b \tag{6}$$

with respect to the production function (4). The (real) rental rate of capital services is r_t, while w_t represents the real household wage. In addition, w_t^e and w_t^b are the compensation given entrepreneurs and banks, respectively, for their labor.

The first-order conditions of this problem with respect to k_{jt}, h_{jt}, h_{jt}^e and h_{jt}^b are respectively:

$$r_t = s_t z_t \theta_k k_{jt}^{\theta_k - 1} h_{jt}^{\theta_h} h_{jt}^{e\ \theta_e} h_{jt}^{b\ \theta_b}; \tag{7}$$

$$w_t = s_t z_t \theta_h k_{jt}^{\theta_k} h_{jt}^{\theta_h - 1} h_{jt}^{e\ \theta_e} h_{jt}^{b\ \theta_b}; \tag{8}$$

$$w_t^e = s_t z_t \theta_e k_{jt}^{\theta_k} h_{jt}^{\theta_h} h_{jt}^{e\ \theta_e - 1} h_{jt}^{b\ \theta_b}; \tag{9}$$

$$w_t^b = s_t z_t \theta_b k_{jt}^{\theta_k} h_{jt}^{\theta_h} h_{jt}^{e\ \theta_e} h_{jt}^{b\ \theta_b - 1}. \tag{10}$$

In these conditions, s_t is the Lagrange multiplier on the production function (4) and represents marginal costs. Combining these conditions, one can show that total production costs, net of fixed costs, are $s_t y_{jt}$.

The price-setting environment is as follows. Each period, a firm receives the signal to reoptimize its price with probability $1 - \phi_p$; with probability ϕ_p, the firm simply indexes

[4] Following Carlstrom and Fuerst (1997), we include labor services from entrepreneurs and bankers in the production function so that these agents always have non-zero wealth to pledge in the financial contract described below. The calibration sets the value of θ_e and θ_b so that the influence of these labor services on the model's dynamics is negligible.

its price to last period's aggregate inflation. After k periods with no reoptimizing, a firm's price would therefore be

$$p_{jt+k} = \prod_{s=0}^{k-1} \pi_{t+s}\, p_{jt}, \tag{11}$$

where $\pi_t \equiv P_t/P_{t-1}$ is the aggregate (gross) rate of price inflation.

A reoptimizing firm chooses $\widetilde{p_{jt}}$ in order to maximize expected profits until the next reoptimzing signal is received. The profit maximizing problem is thus

$$\max_{\widetilde{p}_{jt}} E_t \sum_{k=0}^{\infty} (\beta\phi_p)^k \lambda_{t+k} \left[\frac{p_{jt+k} y_{jt+k}}{P_{t+k}} - s_{t+k} y_{jt+k} \right], \tag{12}$$

subject to (2) and (11).[5]

The first-order condition for $\widetilde{p}_{jt}$ leads to

$$\widetilde{p}_t = \frac{\xi_p}{1-\xi_p} \frac{E_t \sum_{k=0}^{\infty} (\beta\phi_p)^k \lambda_{t+k} s_{t+k} Y_{t+k} \pi_{t+k}^{\xi_p}}{E_t \sum_{k=0}^{\infty} (\beta\phi_p)^k \lambda_{t+k} Y_{t+k} \pi_{t+k}^{\xi_p - 1}}. \tag{13}$$

2.4 Capital good production

Each entrepreneur has access to a technology producing capital goods. The technology is subject to idiosyncratic shocks: an investment of i_t units of final goods returns Ri_t ($R > 1$) units of capital if the project succeeds, and zero units if it fails. The project scale i_t is variable and determined by the financial contract linking the entrepreneur and the bank (discussed below). Returns from entrepreneurial projects are publicly observable.

Different projects are available to the entrepreneurs: although they all produce the same public return R when successful, they differ in their probability of success. Without proper incentive, entrepreneurs may deliberately choose a project with low success probability, because of private benefits associated with that project. Following Holmstrom and Tirole (1997) and Chen (2001), we formalize this moral hazard problem by assuming that entrepreneurs can privately choose between three different projects.

First, the "good" project corresponds to a situation where the entrepreneur "behaves." This project has a high probability of success, denoted α^g, and zero private benefits. The second project corresponds to a "shirking" entrepreneur: it has a lower probability of success $\alpha^b < \alpha^g$, and provides the entrepreneur with private benefits proportional to the project size ($b\, i_t,\ b > 0$). Finally, a third project corresponds to a higher shirking intensity: it has the same low probability of success α^b but provides the entrepreneur with larger private benefits $B\, i_t$, $B > b$.[6]

[5] Time-t profits are discounted by λ_t, the marginal utility of household income.

[6] The existence of two shirking projects allows the model to analyze imperfect bank monitoring.

Banks have access to an imperfect monitoring technology, which can only detect the high-shirking project.[7] Even when monitored by his bank, therefore, an entrepreneur may still choose to run the project with low shirking intensity. A key component of the financial contract discussed below ensures that he has the incentive to behave and choose the "good" project instead.

Bank monitoring is privately costly: to prevent entrepreneurs from choosing the B project, a bank must pay a non-verifiable monitoring cost μi_t in final goods. This creates a second moral hazard problem in our model, between banks and their investors. A bank that invests its own capital in entrepreneur projects, however, lessens this problem, because this bank now has a private incentive to monitor adequately the entrepreneurs it finances. This reassures bank investors and allows the bank to attract loanable funds. The returns in the projects funded by each bank are assumed to be perfectly correlated. Correlated projects can arise because banks specialize (across sectors, regions or debt instruments) to become efficient monitors. The assumption of perfect correlation improves the model's tractability and could be relaxed at the cost of additional computational requirements.[8]

2.5 Financing entrepreneurs: the financial contract

An entrepreneur with net worth n_t wishing to undertake a project of size $i_t > n_t$ needs external financing $i_t - n_t$. The bank provides this financing by combining funds from investors (households) and its own net worth. Denote by d_t the real value of the funds from investors, by a_t the net worth of this bank, and by q_t the price of the capital goods in terms of the final goods.

The optimal financial contract is set in real terms and has the following structure.[9] Assume the presence of inter-period anonymity, which restricts the analysis to one-period contracts.[10] Further, concentrate on equilibria where all entrepreneurs choose to pursue the good project, so that α^g represents the project's probability of success. The contract determines an investment size (i_t), contributions to the financing from the bank (a_t) and the bank's investors (d_t), and how the project's return is shared among the entrepreneur ($R_t^e > 0$), the bank ($R_t^b > 0$) and the investors ($R_t^h > 0$). Limited liability ensures that no agent earns a negative return.

[7] Bank monitoring consists of activities that prevent managers from investing in inferior projects, such as the inspection of cash flows and balance sheets or verifying that firms conform with loan covenants.

[8] Bank capital retains a role in the transmission of shocks so long as banks cannot completely diversify the risk in their lending portfolio. If this were the case, a bank's incentive to monitor would not depend on its capital (Diamond, 1984; Williamson, 1987).

[9] Studying the optimal contract represents a natural starting point in the analysis of the bank capital channel in quantitative models. This could also be a natural benchmark to assess other alternative models with bank capital where financial contracts are specified in nominal terms. The fundamental question of why we see financial contracts written in nominal terms is addressed in a recent paper by Meh et al. (2009).

[10] This follows Carlstrom and Fuerst (1997) and Bernanke et al. (1999).

Formally, the contract seeks to maximize the expected return to the entrepreneur, subject to incentive, participation, and feasibility constraints, as follows:

$$\max_{\{i_t, a_t, d_t, R_t^e, R_t^b, R_t^h\}} \quad q_t \alpha^g R_t^e i_t, \quad \text{s.t.}$$

$$q_t \alpha^g R_t^e i_t \geq q_t \alpha^b R_t^e i_t + q_t b i_t; \tag{14}$$

$$q_t \alpha^g R_t^b i_t - \mu i_t \geq q_t \alpha^b R_t^b i_t; \tag{15}$$

$$q_t \alpha^g R_t^b i_t \geq (1 + r_t^a) a_t; \tag{16}$$

$$q_t \alpha^g R_t^h i_t \geq (1 + r_t^d) d_t; \tag{17}$$

$$a_t + d_t - \mu i_t \geq i_t - n_t; \tag{18}$$

$$R_t^e + R_t^b + R_t^h = R. \tag{19}$$

Condition (14) ensures that entrepreneurs have the incentive to choose the good project: their expected return if they do so is at least as high as the one they would get (inclusive of private benefits) if they undertook the low-shirking intensity project.[11] Condition (15) ensures the bank has an incentive to monitor: its expected return when monitoring is at least as high as the return if not monitoring (in which case the project's probability of success would be low). Next, (16) and (17) are the participation constraints of the bank and the investing households, respectively: they state that the funds engaged earn a return sufficient to cover their (market-determined) returns. These are r_t^a for bank net worth (bank capital) and r_t^d for household investors. Finally, (18) indicates that the bank's loanable funds, net of monitoring, must cover the entrepreneur's financing needs and (19) states that the payments distributed to the three agents when a project is successful add up to total return.

In equilibrium, (14) and (15) hold with equality; solving for the shares R_t^e and R_t^b and introducing these results in (19) yields

$$R_t^e = \frac{b}{\Delta\alpha}; \tag{20}$$

$$R_t^b = \frac{\mu}{q_t \Delta\alpha}; \tag{21}$$

$$R_t^h = R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha}; \tag{22}$$

where $\Delta\alpha \equiv \alpha^g - \alpha^b > 0$.

Note from (20) and (21) that the shares of project return allocated to the entrepreneur and the banker are linked to the severity of the moral hazard problem associated with their decision. In economies where the private benefit b or the monitoring cost μ is higher, the project share allocated to the entrepreneur (or the bank) needs to increase. In turn,

[11] In equilibrium, banks monitor so entrepreneurs do not consider the high-shirking intensity project.

(22) shows that the share of project return that can be credibly promised to households investing in the bank is limited by the two moral hazard problems: if either worsens, the household's share of the project must decrease.

Introducing (22) into the participation constraint (17), which holds with equality, yields

$$(1+r_t^d)d_t = q_t\alpha^g\left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t\Delta\alpha}\right)i_t, \tag{23}$$

and using (18) to eliminate d_t leads to

$$(1+r_t^d)\left[(1+\mu) - \frac{a_t}{i_t} - \frac{n_t}{i_t}\right] = q_t\alpha^g\left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t\Delta\alpha}\right). \tag{24}$$

Finally, solving for i_t in (24) yields

$$i_t = \frac{a_t + n_t}{1+\mu - \frac{q_t\alpha^g}{1+r_t^d}\left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{\Delta\alpha q_t}\right)} = \frac{a_t+n_t}{G_t}, \tag{25}$$

with

$$G_t \equiv 1+\mu - \frac{q_t\alpha^g}{1+r_t^d}\left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{\Delta\alpha q_t}\right).$$

In (25), $1/G_t$ is the leverage achieved by the financial contract over the combined net worth of the bank and the entrepreneur. Note that G_t does not depend on individual characteristics and thus leverage is constant across all contracts in the economy. Expression (25) thus expresses how the project size an entrepreneur can undertake depends positively on the net worth a_t that his bank pledges towards the project, as well as on its own net worth n_t, Further, an increase in the price of capital goods allows for larger entrepreneurial projects (since $\frac{\partial G_t}{\partial q_t} < 0$) while increases in the costs of funds decreases project size (since $\frac{\partial G_t}{\partial r_t^d} > 0$).

One interpretation of this financial contract is that it requires banks to meet solvency conditions that determine how much loanable funds they can attract. These solvency conditions manifest themselves as a market-generated capital adequacy ratio that depends on economy-wide variables like the market return on bank equity (r_t^a) and on bank deposits (r_t^d), as well as on the price of capital goods (q_t). This ratio is defined as

$$\kappa_t \equiv \frac{a_t}{a_t + d_t}. \tag{26}$$

Linearities in the model imply that this ratio depends on aggregate variables only and is thus constant across banks. To see this, use (16)-(17) and (21)-(22) in (26) to get:

$$\kappa_t = \frac{\mu}{\mu + q_t\Delta\alpha\frac{1+r_t^a}{1+r_t^d}\left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{\Delta\alpha q_t}\right)}. \tag{27}$$

Below, we analyze the business cycle behavior of this ratio.

2.6 Households

There exists a continuum of households indexed by $i \in (0, \eta^h)$. Households consume, allocate their money holdings between currency and bank deposits, supply units of specialized labor, choose a capital utilization rate, and purchase capital goods.

The wage-setting environment faced by households (described below) implies that hours worked and labor earnings are different across households. We abstract from this heterogeneity by referring to the results in Erceg et al. (2000) who show, in a similar environment, that the existence of state-contingent securities makes households homogenous with respect to consumption and saving decisions. We assume the existence of these securities and our notation below reflects their equilibrium effect, so that consumption, assets and the capital stock are not contingent on household type i.

Lifetime expected utility of household i is

$$E_0 \sum_{t=0}^{\infty} \beta^t U(c_t^h - \gamma c_{t-1}^h, l_{it}, M_t^c/P_t),$$

where c_t^h is consumption in period t, γ measures the importance of habit formation in consumption, l_{it} is hours worked, and M_t^c/P_t denotes the real value of currency held.

The household begins period t with money holdings M_t and receives a lump-sum money transfer X_t from the monetary authority. These monetary assets are allocated between funds invested at a bank (deposits) D_t and currency held M_t^c so that $M_t + X_t = D_t + M_t^c$. In making this decision, households weigh the tradeoff between the utility obtained from holding currency and the return from bank deposits, the risk-free rate $1 + r_t^d$.[12]

Households also make a capital utilization decision. Starting with beginning-of-period capital stock k_t^h, they can produce capital services $u_t k_t^h$ with u_t the utilization rate. Rental income from capital is thus $r_t u_t k_t^h$, while utilization costs are $\upsilon(u_t) k_t^h$, with $\upsilon(.)$ a convex function whose calibration is discussed in Section 3 below. Finally, the household receives labor earnings $(W_{it}/P_t)\, l_{it}$, as well as dividends Π_t from firms producing intermediate goods.

Income from these sources is used to purchase consumption, new capital goods (priced at q_t), and money balances carried into the next period M_{t+1}, subject to the constraint

$$c_t^h + q_t i_t^h + \frac{M_{t+1}}{P_t} = (1 + r_t^d)\frac{D_t}{P_t} + r_t u_t k_t^h - \upsilon(u_t) k_t^h + \frac{W_{it}}{P_t} l_{it} + \Pi_t + \frac{M_t^c}{P_t}, \qquad (28)$$

with the associated Lagrangian λ_t representing the marginal utility of income. The capital stock evolves according to the standard accumulation equation:

$$k_{t+1}^h = (1 - \delta) k_t^h + i_t^h. \qquad (29)$$

[12] To be consistent with the presence of idiosyncratic risk at the bank level, we follow Carlstrom and Fuerst (1997) and Bernanke et al. (1999) and assume that households deposit money at a large mutual fund, which in turn deposits at a cross-section of banks, diversifying away bank-level risk.

The first-order conditions associated with the choice of c_t^h, M_t^c, u_t, M_{t+1}, and k_{t+1}^h are, respectively,

$$U_1(\cdot_t) - \beta\gamma E_t U_1(\cdot_{t+1}) = \lambda_t; \tag{30}$$

$$U_3(\cdot_t) = r_t^d \lambda_t; \tag{31}$$

$$r_t = \upsilon'(u_t); \tag{32}$$

$$\lambda_t = \beta E_t \left\{ \lambda_{t+1}(1 + r_{t+1}^d)\,(P_t/P_{t+1}) \right\}; \tag{33}$$

$$\lambda_t q_t = \beta E_t \left\{ \lambda_{t+1} \left[q_{t+1}(1-\delta) + r_{t+1} u_{t+1} - \upsilon'(u_{t+1}) \right] \right\}, \tag{34}$$

where $U_j(\cdot_t)$ represents the derivative of the utility function with respect to its jth argument in period t.

Wage Setting

We follow Erceg et al. (2000) and Christiano et al. (2005) and assume that each household supplies a specialized labor type l_{it}, while competitive labor aggregators assemble all such types into one composite input using the technology

$$H_t \equiv \left(\int_0^{\eta^h} l_{it}^{\frac{\xi_w - 1}{\xi_w}} \mathrm{d}i \right)^{\frac{\xi_w}{\xi_w - 1}}, \qquad \xi_w > 1.$$

The demand for each labor type is therefore

$$l_{it} = \left(\frac{W_{i,t}}{W_t} \right)^{-\xi_w} H_t, \tag{35}$$

where W_t is the aggregate wage (the price of one unit of composite labor input H_t). As was the case in the final-good sector, labor aggregators are competitive and make zero profits; imposing this result leads to the following determination for the economy-wide aggregate wage:

$$W_t = \left(\int_0^{\eta^h} {W_{it}}^{1-\xi_w} \mathrm{d}i \right)^{\frac{1}{1-\xi_w}}. \tag{36}$$

Households set wages according to a variant of the mechanism used in the price-setting environment above. Each period, household i receives the signal to reoptimize its nominal wage with probability $1 - \phi_w$, while with probability ϕ_w the household indexes its wage to last period's price inflation, so that $W_{i,t} = \pi_{t-1}\, W_{i,t-1}$. A reoptimizing worker takes into account the evolution of its wage and the demand for its labor (35) during the expected period with no reoptimization. The resulting first-order condition for wage-setting when reoptimizing ($\widetilde{W}_{it}$) yields

$$\widetilde{W}_t = P_{t-1} \frac{\xi_w}{1-\xi_w} \frac{E_t \sum_{k=0}^{\infty} (\beta\phi_w)^k U_2(\cdot_{t+k}) H_{t+k} w_{t+k}^{\xi_w} \pi_{t+k}^{\xi_w}}{E_t \sum_{k=0}^{\infty} (\beta\phi_w)^k \lambda_{t+k} w_{t+k}^{\xi_w} \pi_{t+k}^{\xi_w - 1}},$$

where $w_t \equiv W_t/P_t$ is the real aggregate wage and $U_2(\cdot_t)$ is the derivative of the utility function with respect to hours worked. Once the household's wage is set, hours worked l_{it} is determined by (35).

2.7 Entrepreneurs and Bankers

There exists a continuum of risk neutral entrepreneurs and bankers. Each period, a fraction $1-\tau^e$ of entrepreneurs and $1-\tau^b$ of bankers exit the economy at the end of the period's activities.[13] Exiting agents are replaced by new ones with zero assets.

Entrepreneurs and bankers solve similar optimization problems: in the first part of each period, they accumulate net worth, which they invest in entrepreneurial projects later in that period. Exiting agents consume accumulated wealth while surviving agents save. These agents differ, however, with regards to their technological endowments: entrepreneurs have access to the technology producing capital goods, while bankers have the capacity to monitor entrepreneurs.

A typical entrepreneur starts period t with holdings k_t^e in capital goods, which are rented to intermediate-good producers. The corresponding rental income, combined with the value of the undepreciated capital and the small wage received from intermediate-good producers, constitute the net worth n_t available to an entrepreneur:

$$n_t = (r_t + q_t(1-\delta))\, k_t^e + w_t^e. \tag{37}$$

Similarly, a typical banker starts period t with holdings of k_t^b capital goods and rents capital services to firms producing intermediate goods. Once this bank has received all its different sources of income, it has net worth

$$a_t = (r_t + q_t(1-\delta))\, k_t^b + w_t^b. \tag{38}$$

Each entrepreneur then undertakes a capital-good producing project and invests all available net worth n_t in the project. The entrepreneur's bank also invests its own net worth a_t in the project, in addition to the funds d_t invested by households. As described above, an entrepreneur whose project is successful receives a payment of $R_t^e i_t$ in capital goods whereas the bank receives $R_t^b i_t$; unsuccessful projects have zero return.

At the end of the period, entrepreneurs and bankers associated with successful projects but having received the signal to exit the economy use their returns to buy and consume final (consumption) goods. Successful surviving agents save their entire return (retain all their earnings), which becomes their beginning-of-period real assets at the start of the

[13] This follows Bernanke et al. (1999). Because of financing constraints, entrepreneurs and bankers have an incentive to delay consumption and accumulate net worth until they no longer need financial markets. Assuming a constant probability of death reduces this accumulation process and ensures that a steady state with operative financing constraints exists.

subsequent period, k^e_{t+1} and k^b_{t+1}. This represents an optimal choice since these agents are risk neutral and the high return on internal funds induces them to postpone consumption. Unsuccessful agents neither consume nor save.

2.8 Monetary policy

Monetary policy sets r^d_t, the short-term nominal interest rate, according to the following rule:

$$r^d_t = (1-\rho_r)r^d + \rho_r r^d_{t-1} + (1-\rho_r)\left[\rho_\pi(\pi_t - \overline{\pi}) + \rho_y \hat{y}_t\right] + \epsilon^{mp}_t, \tag{39}$$

where r^d is the steady-state rate, $\overline{\pi}$ is the monetary authority's inflation target, $\hat{y}_t$ represents output deviations from steady state, and ϵ^{mp}_t is an $i.i.d$ monetary policy shock with standard deviation σ^{mp}.[14]

Table 1 below illustrates the sequence of events. The value of aggregate shocks are revealed at the beginning of the period. Intermediate goods are then produced, using capital and labor, and then final goods are produced, using the intermediates. Next, the production of capital goods occurs: households deposit funds in banks, who meet with entrepreneurs to arrange financing. Once financed, entrepreneurs choose which project to undertake and banks choose whether to monitor, consistent with the double moral hazard environment described above. Successful projects return new units of capital goods that are distributed to households, banks and entrepreneurs according to the terms of the financial contract. Exiting banks and entrepreneurs sell their share of capital good in exchange for consumption and households and surviving banks and entrepreneurs make their consumption-savings decisions.

2.9 Aggregation

As a result of the linear specification in the production function for capital goods, in the private benefits accruing to entrepreneurs, and in the monitoring costs facing banks, the distribution of net worth across entrepreneurs and bank capital across banks has no effects on aggregate investment I_t, which is given by the sum of individual projects i_t from (25):

$$I_t = \frac{A_t + N_t}{G_t}, \tag{40}$$

where A_t and N_t denote the aggregate levels of bank capital and entrepreneurial net worth. This represents the inverse supply curve for investment in the economy: in the space (q_t, I_t), an increase in the price q_t causes the quantity supplied I_t to increase, because $\frac{\partial G_t}{\partial q_t} < 0$. Further, a fall in bank capital A_t decreases I_t, i.e. shifts the supply curve to the left.

[14] The targeted rate for r^d_t is achieved with appropriate injections in total money supply $X_t \equiv \overline{M}_{t+1} - \overline{M}_t$, where $\overline{M}_t$ is the total money supply at time t.

Table 1: Timing of Events

- The productivity (z_t) and monetary (ϵ_t^{mp}) shocks are realized.
- Intermediate goods are produced, using capital and labor services; final goods are produced, using intermediates.
- Households deposit savings in banks, who use these funds as well as their own net worth to finance entrepreneur projects i_t.
- Entrepreneurs choose which project to undertake; bankers choose whether to monitor.
- Successful projects return $R\,i_t$ units of new capital, shared between the three agents according to terms of financial contract. Failed projects return nothing.
- Exiting agents sell their capital for consumption goods, surviving agents buy this capital as part of their consumption-savings decision.
- All markets close.

Next, the economy-wide equivalent to the participation constraint of banks (16) defines the aggregate equilibrium return on bank net worth:

$$1 + r_t^a = \frac{q_t \alpha^g R_t^b I_t}{A_t}. \tag{41}$$

Recall also that η^h, η^e and η^b represent the population masses of households, entrepreneurs, and banks, respectively. Aggregate stocks of capital holdings are thus

$$K_t^h = \eta^h k_t^h; \;\; K_t^e = \eta^e k_t^e; \;\; K_t^b = \eta^b k_t^b.$$

Meanwhile, the aggregate levels of entrepreneurial and banking net worth (N_t and A_t) are found by summing (37) and (38) across all agents:

$$N_t = [r_t + q_t(1-\delta)]\, K_t^e + \eta^e w_t^e; \tag{42}$$

$$A_t = [r_t + q_t(1-\delta)]\, K_t^b + \eta^b w_t^b; \tag{43}$$

As described above, successful entrepreneurs and banks survive to the next period with probability τ^e and τ^b, respectively. These agents save all their wealth, because of risk-neutral preferences and the high return on internal funds. Their beginning-of-period assets holdings in $t+1$ are thus

$$K_{t+1}^e = \tau^e \alpha^g R_t^e I_t; \tag{44}$$

$$K_{t+1}^b = \tau^b \alpha^g R_t^b I_t. \tag{45}$$

Combining (40) with (42)-(45) yields the following laws of motion for N_{t+1} and A_{t+1}:

$$N_{t+1} = [r_{t+1} + q_{t+1}(1-\delta)]\,\tau^e \alpha^g R_t^e \left(\frac{A_t + N_t}{G_t}\right) + w_{t+1}^e \eta^e; \tag{46}$$

$$A_{t+1} = [r_{t+1} + q_{t+1}(1-\delta)]\,\tau^b \alpha^g R_t^b \left(\frac{A_t + N_t}{G_t}\right) + w_{t+1}^b \eta^b. \tag{47}$$

Equations (46) and (47) illustrate the interrelated evolution of bank and entrepreneurial net worth. Aggregate bank net worth A_t, through its effect on aggregate investment, affects not only the future net worth of banks, but the future net worth of entrepreneurs as well. Conversely, aggregate entrepreneurial net worth N_t has an impact on the future net worth of the banking sector.

Exiting banks and entrepreneurs consume the value of their available wealth. This implies the following for aggregate consumption of entrepreneurs and banks:

$$C_t^e = (1-\tau^e) q_t \alpha^g R_t^e I_t; \tag{48}$$

$$C_t^b = (1-\tau^b) q_t \alpha^g R_t^b I_t. \tag{49}$$

Finally, aggregate household consumption is

$$C_t^h = \eta^h c_t^h. \tag{50}$$

2.10 The competitive equilibrium

A competitive equilibrium for the economy consists of (i) decision rules for c_t^h, i_t^h, W_{it}, k_{t+1}^h, u_t, M_t^c, D_t, and M_{t+1} that solve the maximization problem of the household, (ii) decision rules for $\widetilde{p_{jt}}$ as well as input demands k_{jt}, h_{jt}, h_{jt}^e, h_{jt}^b that solve the profit maximization problem of firms producing intermediate goods in (12), (iii) decision rules for i_t, R_t^e, R_t^b, R_t^h, a_t and d_t that solve the maximization problem associated with the financial contract, (iv) saving and consumption decision rules for entrepreneurs and banks, and (v) the following market-clearing conditions:

$$K_t = K_t^h + K_t^e + K_t^b; \tag{51}$$

$$u_t K_t^h + K_t^e + K_t^b; = \int_0^1 k_{jt} \mathrm{d}j; \tag{52}$$

$$H_t = \int_0^1 h_{jt} \mathrm{d}j; \tag{53}$$

$$Y_t = C_t^h + C_t^e + C_t^b + I_t + \mu I_t; \tag{54}$$

$$K_{t+1} = (1-\delta) K_t + \alpha^g R I_t; \tag{55}$$

$$\eta^b d_t = \eta^h \frac{D_t}{P_t}; \tag{56}$$

$$\overline{M}_t = \eta^h M_t. \tag{57}$$

Equation (51) defines the total capital stock as the holdings of households, entrepreneurs and banks. Next, (52) states that total capital services (which depend on the utilization rate chosen by households) equals total demand by intermediate-good producers. Equation (53) requires that the total supply of the composite labor input produced according to (35) equals total demand by intermediate-good producers. The aggregate resource constraint is in (54) and (55) is the law of motion for aggregate capital. Finally, (56) equates the aggregate demand of deposits by banks to the supply of deposits by households, and (57) requires the total supply of money $\overline{M}_t$ to be equal to money holdings by households.

3 Calibration

The utility function of households is specified as

$$U(c_t^h - \gamma c_{t-1}^h, l_{i,t}, M_t^c/P_t) = log(c_t^h - \gamma c_{t-1}^h) + \psi log(1 - l_{it}^h) + \zeta log(M_t^c/P_t).$$

The weight on leisure ψ is set to 4.0, which ensures that steady-state work effort by households is equal to 30% of available time. One model period corresponds to a quarter, so the discount factor β is set at 0.99. Following results in Christiano et al. (2005), the parameter governing habits, γ, is fixed at 0.65 and ζ is set in order for the steady state of the model to match the average ratio of $M1$ to $M2$.

The share of capital in the production function of intermediate-good producers, θ^k, is set to the standard value of 0.36. Recall that we want to reserve a small role in production for the hours worked by entrepreneurs and bankers. To this end, we fix the share of the labor input θ^h to 0.6399 instead of $1 - 0.36 = 0.64$, and then set $\theta^e = \theta^b = 0.00005$.The parameter governing the extent of fixed costs, Θ, is chosen so that steady-state profits of the monopolists producing intermediate goods are zero. The persistence of the technology shock, ρ_z, is 0.95, while its standard deviation, σ_z, is 0.0015, which ensures that the model's simulated output volatility equal that of observed aggregate data.

Price and wage-setting parameters are set following results in Christiano et al. (2005). Thus, the elasticity of substitution between intermediate goods (ξ_p) and the elasticity of substitution between labor types (ξ_w) are such that the steady-state markups are 20% in the goods market and 5% in the labor market. The probability of not reoptimizing for price setters (ϕ_p) is 0.60 while for wage setters (ϕ_w), it is 0.64.

To parameterize households' capital utilization decision, we first require that $u = 1$ in the steady-state, and set $\upsilon(1) = 0$. This makes steady state computations independent of $\upsilon(.)$. Next, we set $\sigma_u \equiv \upsilon''(u)(u)/\upsilon'(u) = 0.03$ for $u = 1$. This elasticity implies that capacity utilization's peak response is 0.4% following a one-standard deviation monetary policy shock, matching the empirical estimates reported in Christiano et al. (2005).

The monetary policy rule (39) is calibrated to the estimates in Clarida et al. (2000), so $\rho_r = 0.8$, $\rho_\pi = 1.5$, and $\rho_y = 0.1$. The trend rate of inflation $\overline{\pi}$ is 1.005, or 2% on a

Table 2: Baseline Parameter Calibration

Household Preferences and Wage Setting							
γ	ζ	ψ	β	ξ_w	ϕ_w		
0.65	0.027	4.0	0.99	21	0.6		
Final Good Production							
θ_k	θ_h	θ_e	θ_b	ρ_z	σ_z	ξ_p	ϕ_p
0.36	0.6399	0.00005	0.00005	0.95	0.0015	6	0.64
Capital Good Production and Financing							
μ	α^g	α^b	R	b	τ_e	τ_b	
0.025	0.99	0.75	1.21	0.16	0.78	0.72	
Resulting Steady-State Characteristics							
κ	I/N	BOC	ROE	I/Y	K/Y		
14%	2.0	5%	15%	0.198	11.8		

net, annualized basis. The standard deviation of the monetary policy shock σ^{mp} is set to 0.0016, which ensures that a one-standard-deviation shock corresponds to a 0.6 percentage points change in r_t^d, as in the empirical evidence (Christiano et al., 2005).

The parameters that remain to be calibrated (α^g, α^b, b, R, μ, τ^e, τ^b) are linked to the production of capital goods. We set α^g to 0.9903, so that the (quarterly) failure rate of entrepreneurs is 0.97%, as in Carlstrom and Fuerst (1997). The remaining parameters are such that the model's steady state displays the following characteristics: 1) a 14% capital adequacy ratio (κ), which matches the 2002 average, risk-weighted capital-asset ratio of U.S. banks, according to BIS data; 2) a leverage ratio I/N (the size of entrepreneurial projects relative to their accumulated net worth) of 2.0; 3) a ratio of bank operating costs to bank assets (BOC) of 5%, which matches the estimate for developed economies in Erosa (2001); 4) a 15% annualized return on bank net worth (return on bank equity, ROE), matching the evidence reported by Berger (2003); 5) a ratio of aggregate investment to output of 0.2, and 6) an aggregate capital-output ratio of around 12%. Table 2 summarizes the numerical values of the model parameters. A solution to the model's dynamics is found by linearizing all relevant equations around the steady state using standard methods.

4 Findings

This section presents our main findings about the link between the bank capital channel and macroeconomic fluctuations. First, we show that the presence of an active bank capital channel greatly amplifies and propagates the effects of technology shocks (i.e. supply shocks) on output, investment and inflation, but has a more limited role for the effects of monetary policy shocks (i.e. demand shocks). This suggests that the transmission role of the bank capital channel depends on the nature of the shocks. We also show that when the bank capital channel is active, an economy with more bank capital is better able to absorb negative technology shocks than an economy with less bank capital. Since our model contains several features in addition to financial frictions, such as habit formation in household consumption, price and wage rigidities, and variable capital utilization in production, these results suggest that accounting for the role of bank capital is important when building medium-scale models for monetary policy analysis.

Our second finding is that a financial shock which causes exogenous declines in bank capital leads to sizeable decreases in bank lending, investment and output. This suggests that financial markets can not only amplify and propagate shocks but also be an important source of economic fluctuations.

Third, we compute the model's cyclical properties and show that the influence of the bank capital channel manifests itself in counter-cyclical patterns in the capital adequacy ratios of banks. We document that these patterns broadly match those present in aggregate data, which provides an important validation of the bank capital channel.

4.1 The bank capital channel and the transmission of shocks

In this subsection, we present the impulse response functions of the model following technology shocks and monetary policy shocks and identify the specific role played by the bank capital channel in these responses.

Technology shocks

Figure 1 presents the effects of a one-standard deviation negative technology shock on two economies. The first economy (our baseline) features an active bank capital channel and is labeled the *Bank Capital Channel* Economy. Its responses to the technology shock are in solid lines. The second model economy is similar to the baseline except that the bank capital channel is turned off and this is done by setting the bank monitoring cost to zero (i.e., $\mu = 0$). This economy is labeled the *No Bank Capital Channel* Economy and its responses are displayed in dashed lines.

In both economies, the negative shock decreases the productivity of the intermediate-

good production technology, a decline that is expected to persist for several periods. This reduces the expected rental income from holding capital in future periods so that desired household investment declines, as does the price of capital q_t. The technology shock also has supply-side effects on the production of capital goods. To see this, recall expression (23) arising from the financial contract; expressed with economy-wide variables it becomes

$$(1 + r_t^d)\,\frac{d_t}{I_t} = q_t \alpha^g \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right).$$

The right-hand side of the expression indicates that the decrease in q_t reduces the value of the share of project return reserved for depositors; in turn, the left-hand side shows that to keep the contract incentive-compatible, the weight of deposits in financing a given-size project, d_t/I_t, must fall. In other words, banks must hold more capital per unit of loan. Figure 1 shows that for the Bank Capital Channel Economy, this effect is quantitatively important: the capital adequacy ratio κ_t (measuring holdings of bank capital relative to lending) rises for several periods, reaching a peak increase of 1.2%, 7 periods after the onset of the shock.

Since current-period bank capital A_t, like entrepreneurial net worth N_t, is mainly comprised of retained earnings from previous periods, its immediate reaction to the shock is limited and instead, the increase in κ_t is accommodated by a decrease in bank lending, with associated declines in investment by entrepreneurs.

The decrease in aggregate investment reduces earnings for banks and entrepreneurs, leading to lower levels of net worth in the next period. This sets the stage for second-round effects on investment in subsequent periods, as the lower levels of bank net worth further reduce the ability of banks to attract loanable funds. As a result, investment continues to fall for an extended period, bottoming out 19 periods after the onset of the shock, at a maximum decrease of almost 8.5%. Bank and entrepreneur net worth also experience persistent declines alongside aggregate investment. Output declines markedly as well, bottoming out 18 periods after the onset of the shock, with a 2.2% decrease.

Finally, the negative shock puts upward pressure on inflation. In resaction, monetary authorities follow a tight policy after the onset of the shock, increasing rates by as much as 82 basis points. Such a policy stance represents an additional source of weakness in the economy but limits the rise in inflation to just under 80 basis points on an annualized basis.

The responses to the shocks are markedly different in the No Bank Capital Channel Economy (dashed lines). Recall that in this economy, the bank capital channel is not active because bank monitoring cost μ is 0. This means that bank capital is not needed to attract loanable funds since the agency problem between bankers and depositors is not present. Hence, the dynamics of bank capital stop affecting the economy's responses to the shock. Figure 1 shows that as a result, the economic downturn is both less pronounced

and less persistent. The decrease in investment in the No Bank Capital Channel economy is only 4.5% at its maximum, one half the decrease experienced by the Bank Capital Channel Economy. The response of output is also dampened, with a peak decline of only 1.5%, significantly smaller than the one observed in the Bank Capital Channel Economy. In addition, investment and output bottom out earlier in the No Bank Capital Economy, after 13 periods and 11 periods respectively, compared to 19 periods (investment) and 18 periods (output) in the Bank Capital Channel Economy. The different responses of the two economies have implications for the conduct of monetary policy: the more modest declines of bank lending and economic activity in the No Bank Capital Channel Economy reduce inflationary pressures, which allows monetary authorities to set policy more moderately. As a result, short term rates increase by under 60 basis points in the No Bank Capital Channel Economy, and the increase in inflation is limited.

In summary, an active bank capital channel amplifies and propagates the negative impacts of the technology shock, which results in sizeable decreases in investment and output. When the bank capital channel is not active, the shock's impact on the economy is dampened and the declines in investment, output, and inflation are more modest. These results are consistent with the evidence that the evolution of bank capital significantly affects bank lending and real economic activity (Peek and Rosengren, 1997, 2000).

Monetary policy shocks

Figure 2 presents the responses to a one-standard deviation negative monetary policy shock, for the Bank Capital Channel Economy (solid lines) and for the No Bank Capital Channel Economy (dashed lines). The shock causes an increase in the short term rate r_t^d of just under 60 basis points, consistent with the VAR-based evidence in Christiano et al. (2005).

In the Bank Capital Channel Economy where the bank capital channel is active, the tightening has negative effects on the supply of capital goods. This occurs because the increase in r_t^d increases the costs of loanable funds, leading banks to rely relatively more on their own capital to lend: this requires a decline in the ratio d_t/I_t and an increase in the capital to loan ratio κ_t, which increases by 1% on impact. Because bank capital cannot react much initially, bank lending decreases, which also leads to investment decreases. These declines in investment and bank lending following a negative monetary policy shock are consistent with empirical results in Gertler and Gilchrist (1994), Kashyap and Stein (2000) and Kishan and Opiela (2000) concerning firms and banks likely to be financially constrained.

Again, lower investment causes declines in bank earnings and thus bank capital decreases in subsequent periods, which propagate the negative effects of the shock through

time: investment falls for 4 periods before reaching its maximum decrease of 1.8%. Note that this pronounced hump-shaped pattern in aggregate investment does not result from capital adjustment costs, as in Christiano et al. (2005), but instead from the joint influence of bank capital and entrepreneurial net worth. We investigate this hump-shaped response of investment in more detail in Section 5 below.

Turning to the responses of the No Bank Capital Channel Economy (dashed lines), Figure 2 shows that turning off the bank capital channel dampens the fluctuations associated with the negative monetary policy shock, although this dampening effect is less than it was following the negative technology shock. The peak decline in investment occurs earlier (3 periods after the shock) and is smaller (1.6%) in the No Bank Capital Channel Economy than was the case in the Bank Capital Channel Economy. Similarly, output bottoms out after 3 periods, earlier than it did in the Bank Capital Channel Economy.

Overall, Figure 1 and Figure 2 show that introducing the bank capital channel ($\mu > 0$) greatly amplifies and propagates the effects of technology shocks (i.e. supply shocks) and plays a more limited role in amplifying the effects of monetary policy shocks (i.e. demand shocks).

An experiment with more bank capital

A subsequent question that emerges is whether a higher availability of bank capital can mitigate the amplification and propagation of shocks when the bank capital channel is active ($\mu > 0$). We address this issue by conducting another thought experiment, in which we compare the baseline economy to an alternative, hypothetical economy. This hypothetical economy is also similar to the baseline one except that in this new economy an exogenous endowment of ($e^b > 0$) is given to surviving and newborn bankers. In the baseline, $e^b = 0$. In the alternative economy, e^b is set such that the steady-state bank-capital asset ratio is higher than in the baseline economy, and equals 20%. As such, bank capital is more abundant in the alternative economy, for a given level of moral hazard.

To construct the responses of this alternative economy to shocks, the only equations slightly modified are the law of motion for bank capital (47), and the resource constraint (54), and they become respectively:

$$\begin{aligned} A_{t+1} &= [r_{t+1} + q_{t+1}(1-\delta)]\,\tau^b \alpha^g R_t^b \left(\frac{A_t + N_t}{G_t}\right) + w_{t+1}^b \eta^b + \eta^b e^b, \\ Y_t + \eta^b e^b &= C_t^h + C_t^e + C_t^b + I_t + \mu I_t, \end{aligned}$$

where the new term in both equations is $\eta^b e^b$. Therefore, for a given financial friction between bankers and depositors (i.e., $\mu > 0$), the alternative economy receiving e^b has more bank capital than the baseline economy.

Figure 3 reports the responses of the baseline economy (solid lines) and the hypothetical economy with more bank capital (dashed lines) following a negative technology shock. The figure shows that the economy with more bank capital is better able to absorb the adverse effects of the shock, and bank lending, investment and output decline less than they do in the baseline economy. Figure 4 reports the effects of a negative monetary policy shocks for the baseline economy and the hypothetical economy with more bank capital: the figure shows that the effects following monetary policy shocks are still minor.

4.2 A credit crunch: shock to the banking sector

We now consider the effects of financial shocks that lead to exogenous declines in bank capital (bank net worth). Following the theoretical contribution of Holmstrom and Tirole (1997), this shock might be interpreted as a 'credit crunch', caused perhaps by sudden deteriorations in the balance sheets of banks, as loan losses and asset writedowns reduce bank equity and net worth. Recent upheavals in financial markets worldwide, characterized by growing loan loss provisions, large asset writedowns and dramatic reductions in profits of financial institutions, appear to reflect disturbances of this kind.

We capture the effects of such episodes by assuming that the real assets of the banking sector may be subject to episodes of accelerated depreciation. In this context, aggregate bank net worth defined in (43) becomes

$$A_t = [r_t + q_t(1 - \delta x_t)]\, K_t^b + \eta^b w_t^b,$$

where x_t represents the occurrence of such accelerated depreciation of bank net worth and follows a AR(1) exogenous process. A positive shock to x_t thus decreases the value of bank assets and leads to exogenous declines in bank capital.

Figure 5 depicts the effects of such a shock, whose size has been chosen to set the initial decrease in bank capital around 5%. This magnitude appears in line with recent evidence on the likely effects of financial distress episodes. The sudden scarcity of bank capital acts like a negative supply shock in the production of capital goods, because it reduces the banking sector's capacity to arrange financing for entrepreneurs. As a result, bank lending to entrepreneurs declines and so does investment, which falls by 0.4% on impact. The reduced availability of bank capital also means that banks lend less for a given amount of entrepreneurial net worth, which explains the drop in the capital-asset ratio κ_t, which falls by around 4%.

The mechanism by which this shock is transmitted to future periods is as discussed above: the decrease in investment depresses bank earnings, which sets the stage for further decreases in bank capital and thus investment in subsequent periods. These declines occur for an extended period of time: investment bottoms out 13 periods after the onset of the shock, with a decline of 2.5%. Output also falls for several periods, reaching a

maximum decline of 0.5% 13 periods after the initial shock. Overall, the episode of financial distress captured by the shock leads to a recessionary period, with output and investment falling significantly for several periods. However, aggregate consumption increases slightly during this episode. This slight increase results from the combination of two effects. First, bank and entrepreneurs' consumption decreases alongside economic activity. Second, household consumption rises, because the shock to bank capital increases the price of capital goods and thus leads households to substitute towards consumption. Since the weight of households is higher in our economy, this increase causes the rise in aggregate consumption. The response of household consumption is similar to what occurs after negative investment-specific technology shocks (Fisher, 2006), as both types of shocks have similar negative effects on the supply of capital goods. Finally, the shock creates some mild inflationary pressures and in reaction, the interest rate increase slightly.

4.3 Cyclical properties of capital-asset ratios

In Figure 1 and Figure 2, the capital adequacy (capital-asset) ratios of banks increase when economic activity weakens and decrease when activity recovers. To test the validity of this counter-cyclical pattern, Table 3 compares model-based movements in capital-asset ratios with those from actual data from the U.S. banking system. If these movements are comparable, it provides evidence in favor of our model and suggests that market discipline affects banks' decisions on lending and capitalization.

First, we document the facts. Panel A of Table 3 shows that bank capital-asset ratios in the United States are one-third as volatile as output, while investment and bank lending are over four times as volatile.[15] Movements in capital-asset ratios are also persistent, with one-step and two-step autocorrelations of 0.9 and 0.8, respectively. Next, capital-asset ratios are countercyclical with respect to output, but also with respect to investment and bank lending. Moreover, these negative correlations extend to various leads and lags. In short, capital-asset ratios are not very volatile, are persistent, and are negatively related to economic activity. Importantly, the counter-cyclical pattern depicted in Table 3 is also present when using alternative data sources (Adrian and Shin, 2008).

Panel B presents the results of repeated simulations of our model economy: it shows a broad concordance between the model's predictions for κ_t and the observed behavior of the capital-asset ratios of banks. Notably, the model replicates well the high serial correlation of this ratio and its counter-cyclical movements with respect to output, investment, and

[15] The bank capital-asset ratio is the sum of *tier1* and *tier2* capital, over risk-weighted assets. *tier1* capital is the sum of equity capital and published reserves from post-tax retained earnings; *tier 2* capital is the sum of undisclosed reserves, asset revaluation reserves, general provisions, hybrid debt/equity capital instruments, and subordinated debt. The risk weights follow the Basel I classifications and are: 0% on cash and other liquid instruments, 50% on loans fully secured by mortgage on residential properties, and 100% on claims to the private sector.

Table 3. Cyclical Properties of the Capital-Asset Ratio κ_t

Variable	$\frac{\sigma(X)}{\sigma(GDP)}$	*Correlation of Capital-Asset Ratio with:* X_{t-2}	X_{t-1}	X_t	X_{t+1}	X_{t+2}
Panel A: US Economy (1990:1-2005:1)						
Banks' Capital-Asset Ratio	0.34	0.79	0.90	1.00	0.90	0.79
Investment	4.26	−0.45	−0.42	−0.36	−0.25	−0.17
GDP	1.00	−0.36	−0.31	−0.23	−0.12	−0.07
Bank Lending	4.52	−0.52	−0.62	−0.70	−0.69	−0.67
Panel B: Model Economy						
Banks' Capital-Asset Ratio (κ_t)	1.52	0.57	0.83	1.00	0.83	0.57
Investment	3.72	0.31	0.06	−0.22	−0.43	−0.56
GDP	1.00	0.03	−0.23	−0.50	−0.64	−0.70
Bank Lending	3.85	0.21	−0.06	−0.36	−0.51	−0.61

Notes: Capital-Asset Ratio: *tier1* + *tier2* capital over risk-weighted assets (source BIS); Investment: Fixed Investment, Non Residential, in billions of chained 1996 Dollars (source BEA); GDP: Gross Domestic Product, in billions of chained 1996 Dollars (source BEA); Bank Lending: Commercial and Industrial Loans Excluding Loans Sold (source BIS). GDP, investment, and bank lending are expressed as the log of real, per-capita quantity. All series are detrended using the HP filter. For the model economy, results are averages, over 500 repetitions, of simulating the model for 100 quarters, filtering the simulated data, and computing the appropriate moments.

bank lending. The model generates too much volatility in κ_t however, relative to observed data, perhaps as a result of our framework's sole reliance on market discipline to motivate solvency conditions on banks. Adding exogenous regulatory capital requirements would possibly lower the volatility in capital-to-asset ratios, by inciting banks to keep a capital buffer in order to avoid hitting regulatory capitalization floors.

Overall, the general concordance between model and data constitutes an important test of the validity of our framework. Further, it suggests that market discipline may have played an important, though not exclusive, role in shaping the evolution of bank capital and capital-asset ratios over the recent monetary history.[16]

[16] This finding provides some support to dispositions of the updated Basle accord on capital requirements calling for market discipline to constitute one of the three 'pillars' of bank capital regulation.

5 Sensitivity Analysis

This section assesses the sensitivity of our findings to the parameter values for the monetary policy rule and the probability that banks exit the economy. The section also shows how the hump-shaped response of investment to shocks is linked to both the presence of the bank capital channel and the influence of entrepreneurial net worth.

An alternative monetary policy rule

To investigate the robustness of the bank capital channel to the specification of monetary policy, we modify the specification of the monetary policy rule (39). Instead of using the empirical estimates of Clarida et al. (2000), we set the policy response to inflation ρ_π to a high value ($\rho_\pi = 10$) and all other coefficients of the rule to zero: this implies that the monetary authority reacts very strongly to any deviation of inflation from its target and thus proxies for a strict inflation-targeting policy. Using this monetary policy rule, Figure 6 shows the responses of the Bank Capital Channel Economy (solid lines) and the No Bank Capital Channel Economy (dashed lines), respectively, after a one-standard deviation negative technology shock. We focus on the responses following technology shocks for this experiment as our findings above have established that the bank capital channel is at its most important when propagating these types of shocks.

Figure 6 shows that our findings are robust to the specification of the monetary policy rule, as the bank capital channel continues to play a key role in amplifying and propagating shocks: the responses of output and investment in the Bank Capital Channel Economy exhibit more pronounced and more persistent declines following the shocks, than those in the No Bank Capital Channel Economy, much like they did in Figure 1. The main difference between Figure 6 and Figure 1 is that the response of inflation is muted in Figure 6, because of the strong focus of monetary authorities on this variable under the alternative monetary policy rule.

Lower value of τ^b

The parameter τ^b governs the fraction of bank earnings that are kept as retained earnings for building bank capital and, as such, can be broadly interpreted as a "dividend policy" of bankers. Although our calibration exercise jointly assigns parameter values, we find that our calibrated value of $\tau^b = 0.72$ is particularly important to match observed returns on bank equity. To assess the sensitivity of our results to the value of τ^b, we explore the consequences of using a lower value of $\tau^b = 0.6$, consistent with the one used by Aikman and Paustian (2006). A lower value of τ^b weakens the link between current earnings in the banking sector and bank capital in future periods. Since this link is a key ingredient in the bank capital channel, we expect that a lower value of τ^b will reduce the effectiveness of this channel in the propagation of shocks. Figure 7 shows that it is

the case. The figure displays the responses of three economies to a one-standard deviation adverse technology shock. First, the responses arrived at using our baseline calibration are in solid lines. Next, the responses of an economy which uses the lower value of $\tau^b = 0.6$ are in dotted lines. Consistent with our expectations, the strength of the bank capital channel in propagating the shock is reduced and the responses of the economy to the shock are thus less persistent. A subsequent, natural question that emerges is whether the bank capital channel remains important with this lower value of τ^b. To answer this question, the dashed lines in the figure display the responses of an economy where the bank capital channel has been removed (i.e. $\mu = 0$) from the economy with the lower value of τ^b. Comparing the dotted and dashed lines shows that the bank capital channel remains a key ingredient in the propagation and amplification of shocks.[17]

The response of investment to shocks

In Figure 1 and Figure 2, the response of investment to shocks displays a pronounced hump-shaped pattern; this pattern does not result from capital adjustment costs, absent in our model, but rather is shaped by the dynamics of bank capital and entrepreneurial net worth. To see this, recall that next period's bank capital and entrepreneurial net worth are accumulated through current retained earnings, so that additional bank capital and entrepreneurial net worth cannot readily be raised after a shock. It is these sluggish responses of bank capital and entrepreneurial net worth that generates the hump-shaped pattern of investment: the influence of entrepreneurial net worth plays a part, consistent with Carlstrom and Fuerst (1997), but the bank capital channel adds an extra layer of delay in investment's reaction to shocks.

The joint importance of bank capital and entrepreneurial net worth for creating the hump-shaped response of investment to shocks is best illustrated by Figure 8, which depicts three set of responses following a one-standard deviation negative monetary policy shock. First, the investment response for the baseline calibration is in solid lines and reproduces the one in Figure 2: this response is affected both by the bank capital channel and the influence of entrepreneurial net worth and features the hump-shaped response already discussed in Section 4. The dotted line is the investment response in the economy when the bank capital channel is removed ($\mu = 0$): the hump- shaped response is still present, but less pronounced. Third, the dashed lines depict the investment response in the economy when both the bank capital channel and the influence of entrepreneurial net worth are removed (that is, $\mu = 0$ and $b = 0$ respectively). The hump-shaped response of investment to the monetary policy shock is now eliminated.

[17] Similarly, an experiment with a lower value of τ^e shows that our results about the bank capital channel are broadly robust to the calibrated value of τ^e.

6 Conclusion

This paper presents a dynamic general equilibrium model that emphasizes the role of bank capital in the transmission of shocks. Bank capital is important in the model because it mitigates moral hazard between banks and the investors who supply loanable funds. As a result, the capital position of banks affects their ability to attract loanable funds and lend, and therefore influences macroeconomic fluctuations.

We show that the presence of this bank capital channel of transmission amplifies and propagates the effects of technology shocks (i.e., supply shocks) on output, investment and inflation but has a more limited role for the effects of monetary policy shocks (i.e., demand shocks). One key aspect of the framework is that it generates movements in bank capital adequacy ratios that covary negatively with the cycle: we show that these movements broadly match those observed in actual economies, an important test of our framework's validity. Finally, we show that adverse financial shocks that cause sudden decreases in bank capital lead to sizeable declines in bank lending and economic activity.

This paper represents one step in establishing a framework to study the links between the balance sheet of banks and economic fluctuations. In ongoing work, we are extending our framework to allow movements in capital-asset ratios to reflect both the influence of regulatory requirements and the market discipline emphasized in this paper. Adding explicit regulatory requirements into our framework will enrich the analysis and possibly affect the business cycle properties of capital adequacy ratios. Other potential extensions include introducing bank-level heterogeneity in the model and study its resulting influence on aggregate bank lending, and using our framework to study the important role played by banks in asset maturity transformation. Finally, studying the implications of financial contracts set in nominal terms is an important avenue for further work: in our framework where banks are both lenders and borrowers, the net quantitative implications of nominal contracts remains uncertain.

References

T. Adrian and H. S. Shin. Liquidity, monetary policy, and financial cycles. Federal Reserve Bank of New York *Current Issues in Economics and Finance*, January-February 2008.

D. Aikman and M. Paustian. Bank capital, asset prices and monetary policy. Bank of England Working Paper 305, August 2006.

A. N. Berger. The economic effects of technological progress: Evidence from the banking industry. *Journal of Money, Credit and Banking*, 35:141–176, 2003.

B. S. Bernanke and C. S. Lown. The credit crunch. *Brookings Papers on Economic Activity*, 2:205–39, 1991.

B. S. Bernanke, M. Gertler, and S. Gilchrist. The financial accelerator in a quantitative business cycle framework. In J. B. Taylor and M. Woodford, editors, *Handbook of Macroeconomics*, Amsterdam, 1999. Elsevier Science.

C. T. Carlstrom and T. S. Fuerst. Agency costs, net worth, and business fluctuations: A computable general equilibrium analysis. *The American Economic Review*, 87:893–910, 1997.

C. T. Carlstrom and T. S. Fuerst. Agency costs and business cycles. *Economic Theory*, 12:583–597, 1998.

N.-K. Chen. Bank net worth, asset prices and economic activity. *Journal of Monetary Economics*, 48:415–436, 2001.

L. J. Christiano, R. Motto, and M. Rostagno. Financial factors in economic fluctuations. Manuscript, October 2008.

L.J. Christiano, M. Eichenbaum, and C. L. Evans. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113:1–45, 2005.

R. Clarida, Galí. J., and M. Gertler. Monetary policy rules and macroeconomic stability: Evidence and some theory. *Quartely Journal of Economics*, 115:147–180, 2000.

V. Cúrdia and M. Woodford. Credit frictions and optimal monetary policy. Manuscript, October 2008.

D. Diamond. Financial intermediation and delegated monitoring. *Review of Economic Studies*, 51:393–414, 1984.

C. J. Erceg, D. Henderson, and A. T. Levin. Optimal monetary policy with staggered wage and price contracts. *Journal of Monetary Economics*, 46:281–313, 2000.

A. Erosa. Financial intermediation and occupational choice in development. *Review of Economic Dynamics*, 4:303–334, 2001.

J. D. M. Fisher. The dynamic effects of neutral and investment-specific technology shocks. *Journal of Political Economy*, 114:413–451, 2006.

M. Gertler and S. Gilchrist. Monetary policy, business cycles, and the behavior of small manufacturing firms. *Quartely Journal of Economics*, 109:309–340, 1994.

M. Goodfriend and B. McCallum. Banking and interest rates in monetary policy analysis: A quantitative exploration. *Journal of Monetary Economics*, 54:1480–1507, 2007.

B. Holmstrom and J. Tirole. Financial intermediation, loanable funds, and the real sector. *Quartely Journal of Economics*, 112:663–691, 1997.

M. Iacoviello. House prices, borrowing constraints, and monetary policy in the business cycle. *The American Economic Review*, 95:739–764, 2005.

A. K. Kashyap and J. C. Stein. What do a million observations on banks say about the transmission of monetary policy? *The American Economic Review*, 90:407–428, 2000.

R. P. Kishan and T. P. Opiela. Bank size, bank capital, and the bank lending channel. *Journal of Money, Credit, and Banking*, 32:121–141, 2000.

N. Kiyotaki and J. Moore. Credit cycles. *Journal of Political Economy*, 105:211–248, 1997.

B. Markovic. Bank capital channels in the monetary transmission mechanism. Bank of England Working Paper 313, November 2006.

C. Meh and K. Moran. Bank capital, agency costs, and monetary policy. Bank of Canada Working Paper 2004-6, 2004.

C. Meh, V. Quadrini, and Y. Terajima. Real effects of price stability with endogenous nominal indexation. Bank of Canada Working Paper No. 2009-16, 2009.

J. Peek and E. S. Rosengren. The international transmission of financial shocks: The case of Japan. *The American Economic Review*, 87:495–505, 1997.

J. Peek and E. S. Rosengren. Collateral damage: Effects of the Japanese bank crisis on real activity in the United States. *The American Economic Review*, 90:30–45, 2000.

F. Smets and R. Wouters. Shocks and frictions in US business cycles: a Bayesian DSGE approach. *The American Economic Review*, 97:586–606, 2007.

S. J. Van den Heuvel. Banking conditions and the effects of monetary policy: Evidence from U.S. states. Manuscript, Wharton School, January 2002.

S. J. Van den Heuvel. Do monetary policy effects on bank lending depend on bank capitalization? Manuscript, Wharton School, September 2007.

S. J. Van den Heuvel. The welfare costs of bank capital requirements. *Journal of Monetary Economics*, 55:298–320, 2008.

S. Williamson. Financial intermediation, business failures, and real business cycles. *Journal of Political Economy*, 95:1196–1216, 1987.

Figure 1. Responses to a Negative Technology Shock

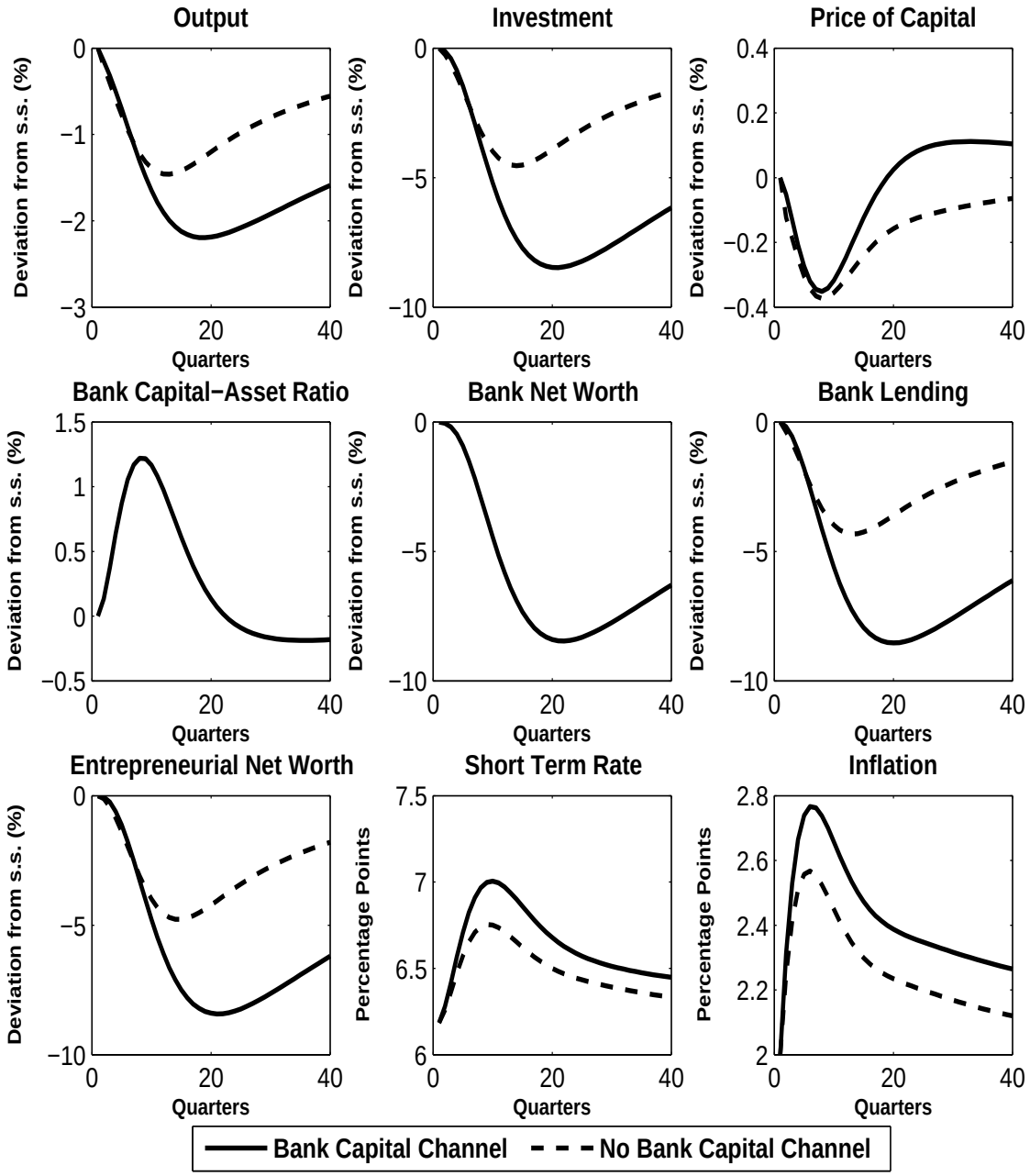

Figure 2. Responses to a Negative Monetary Policy Shock

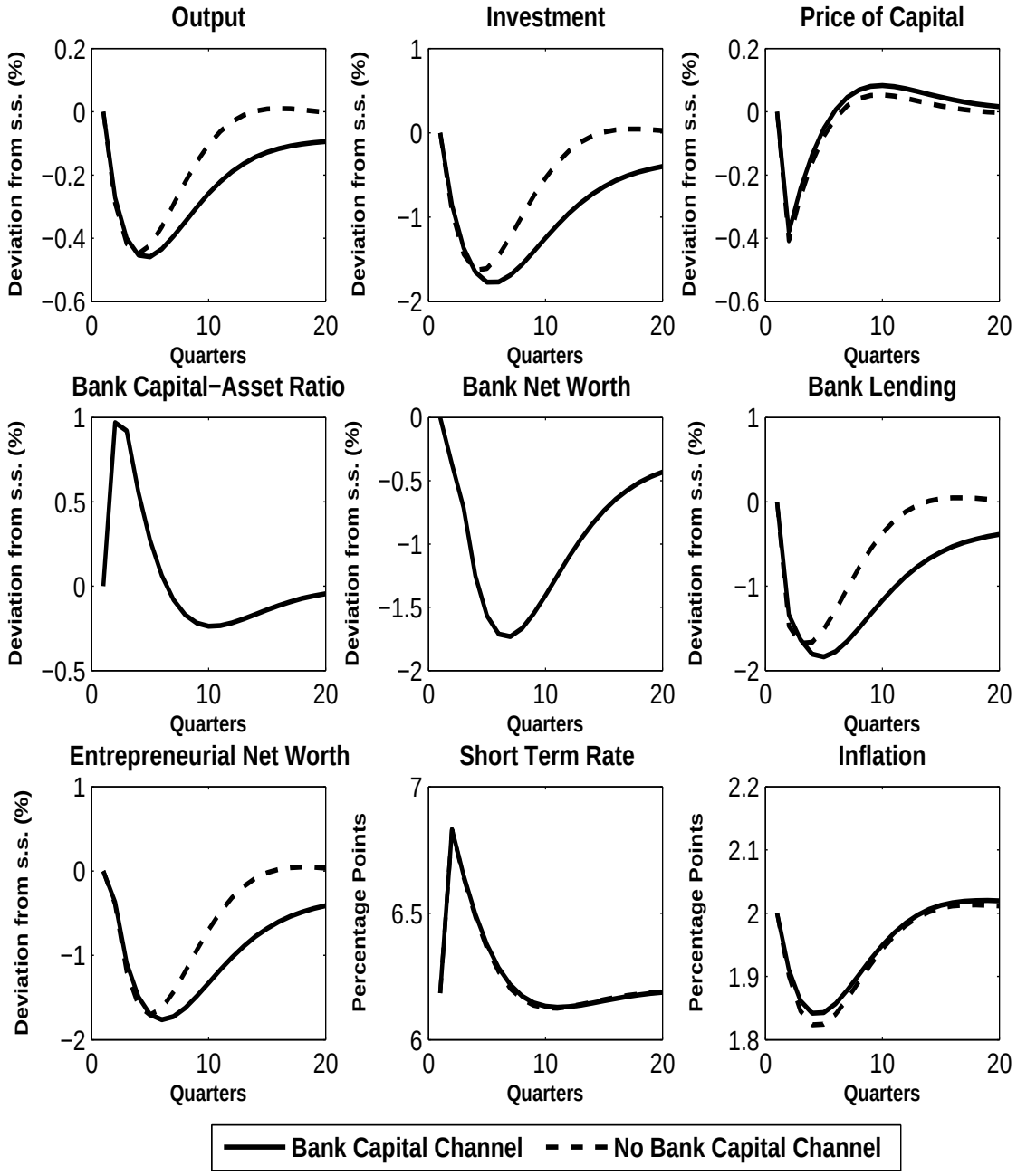

Figure 3. Responses to a Negative Technology Shock: Baseline and Economy with more Bank Capital

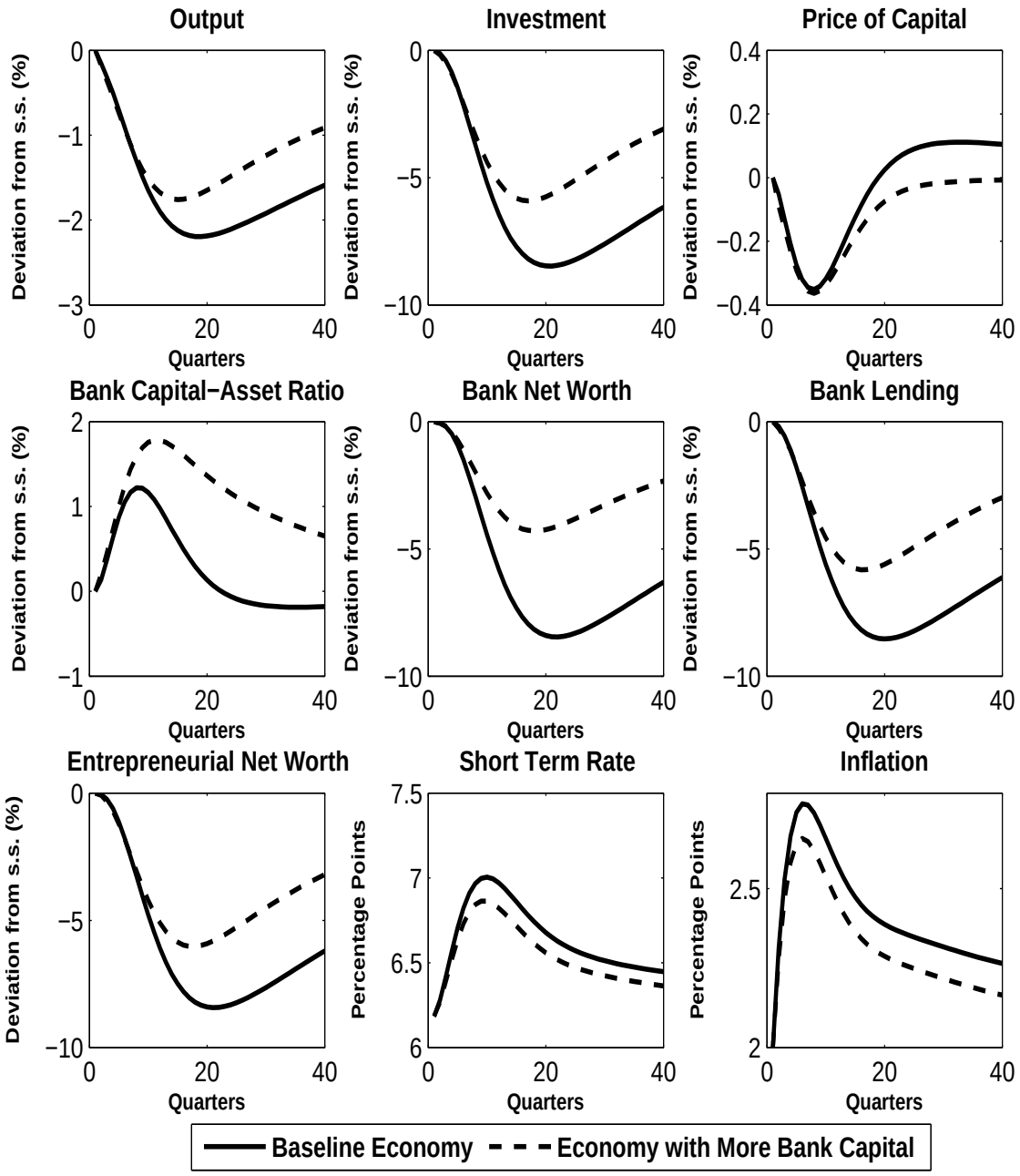

Figure 4. Responses to a Negative Monetary Policy Shock: Baseline and Economy with more Bank Capital

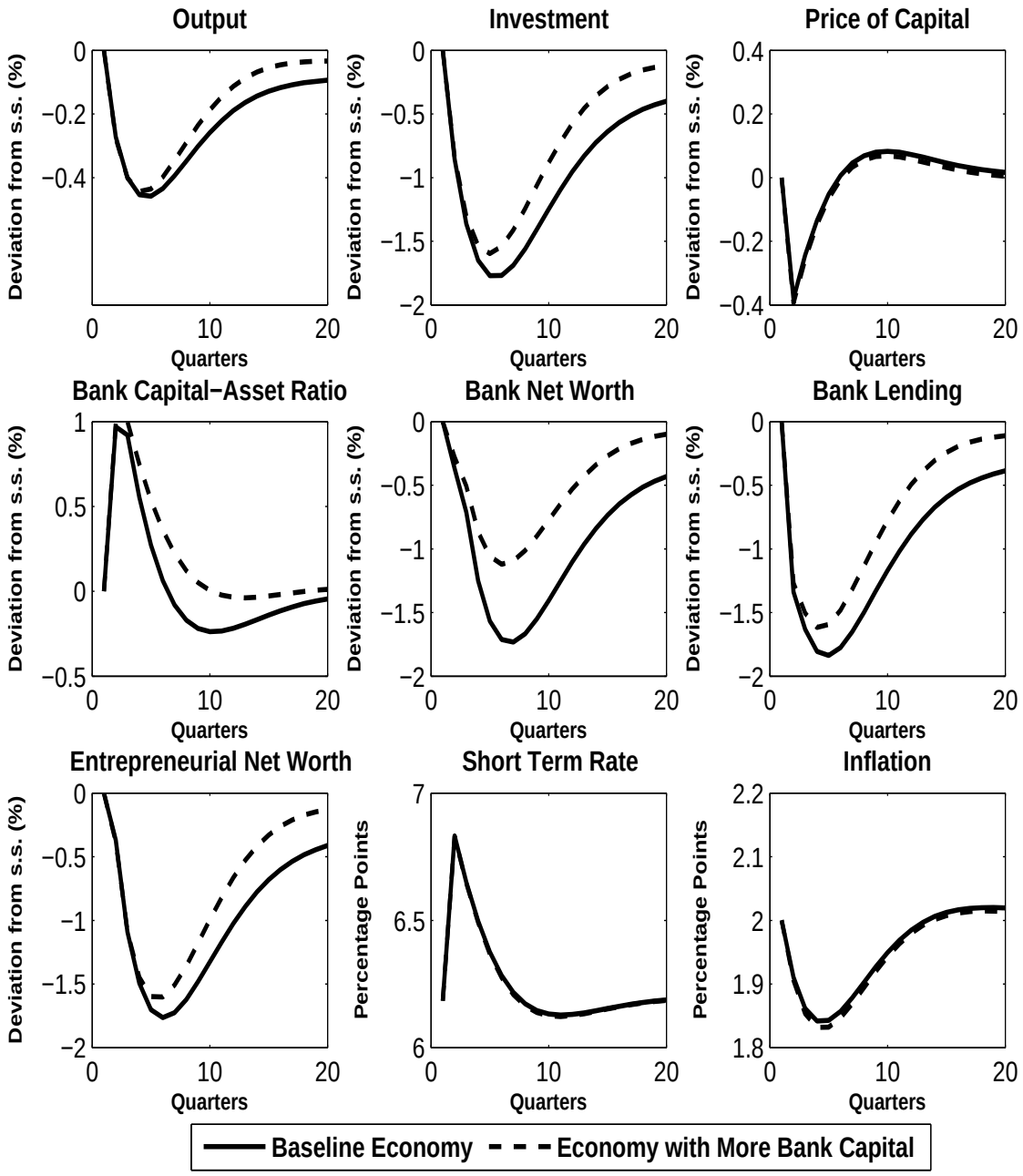

Figure 5. Responses to a Negative Shock to Bank Capital

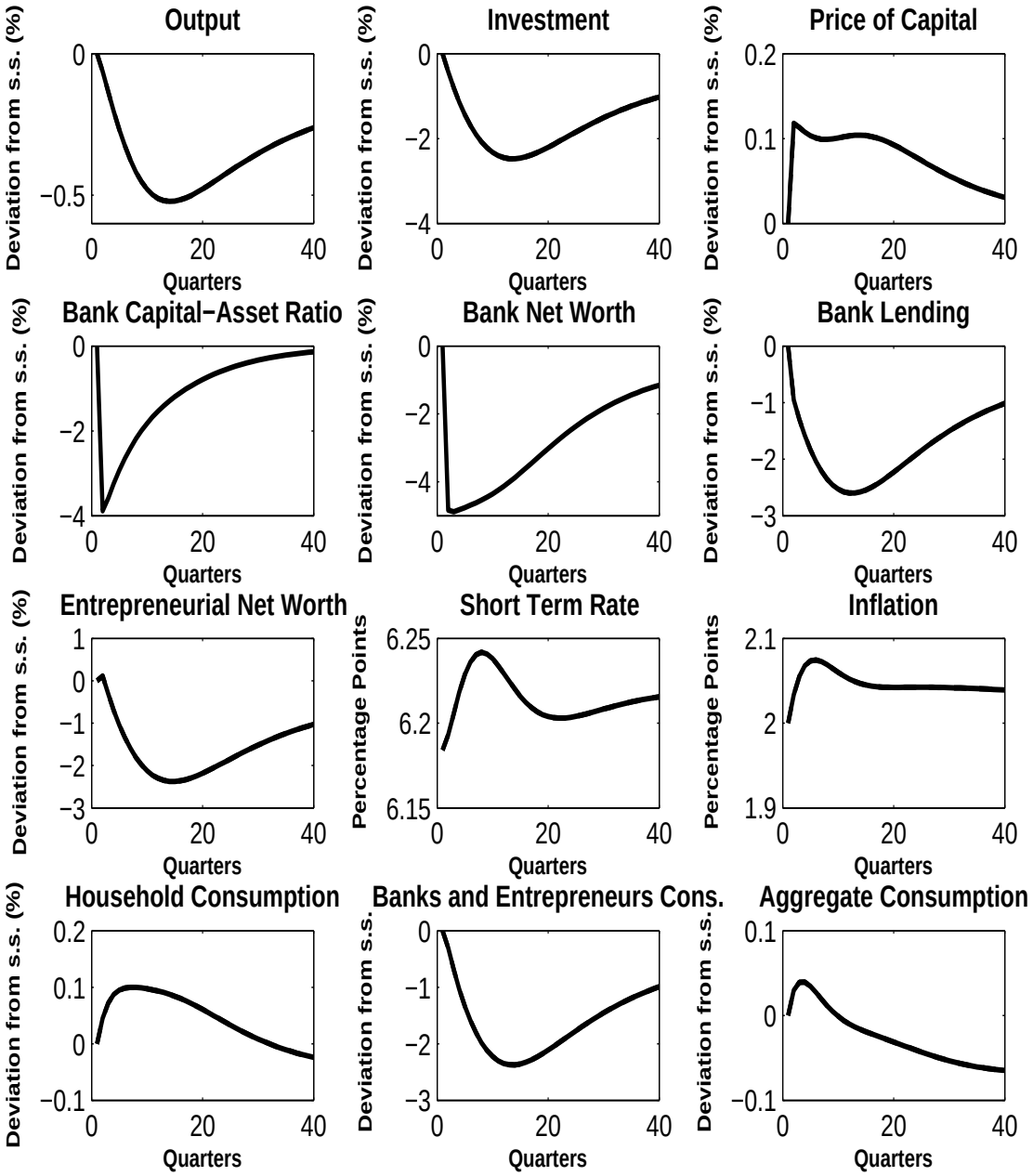

Figure 6. Responses to a Negative Technology Shock
Alternative Monetary Policy Rule

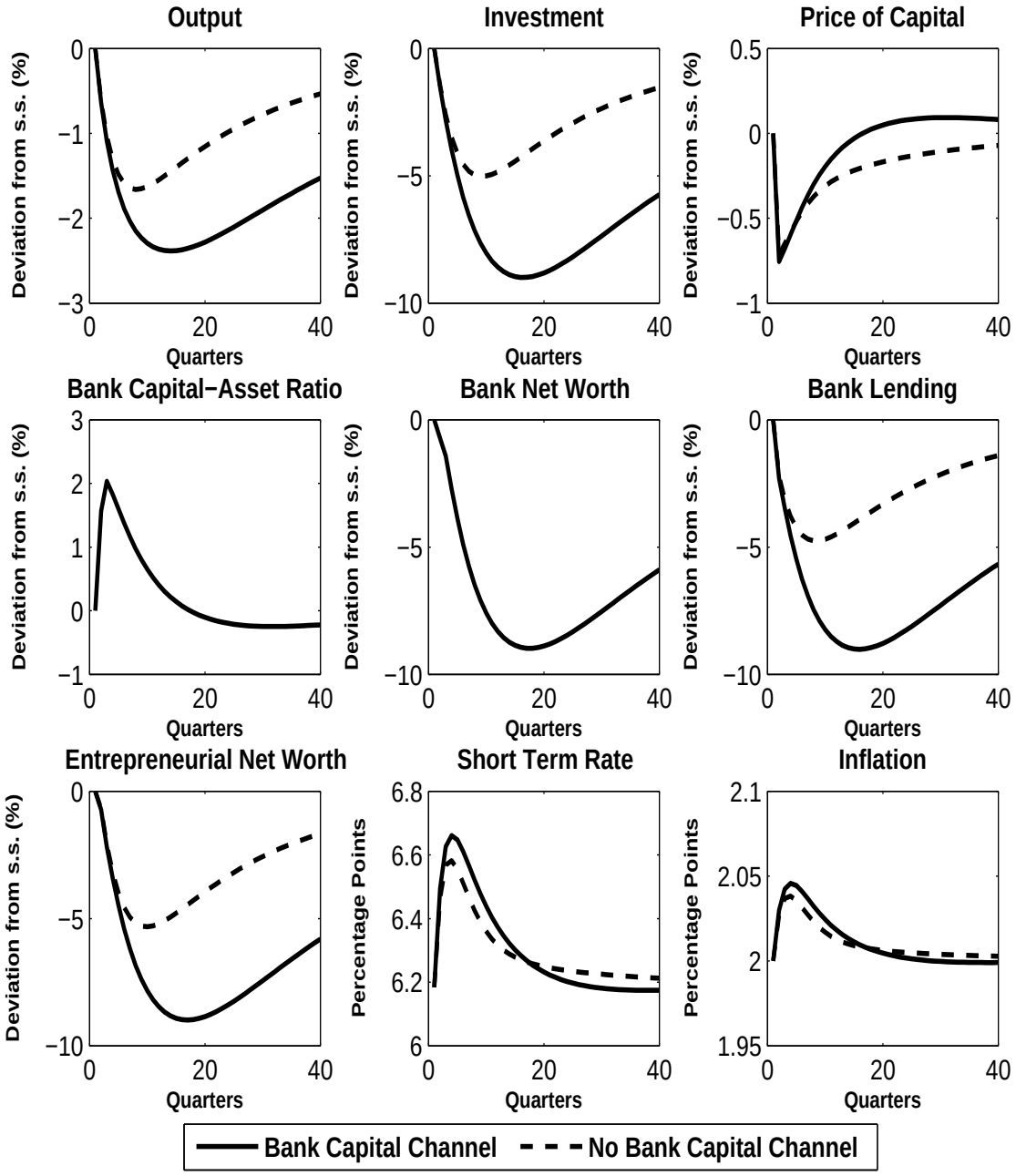

Figure 7. Responses to a Negative Technology Shock
Lower value of τ^b

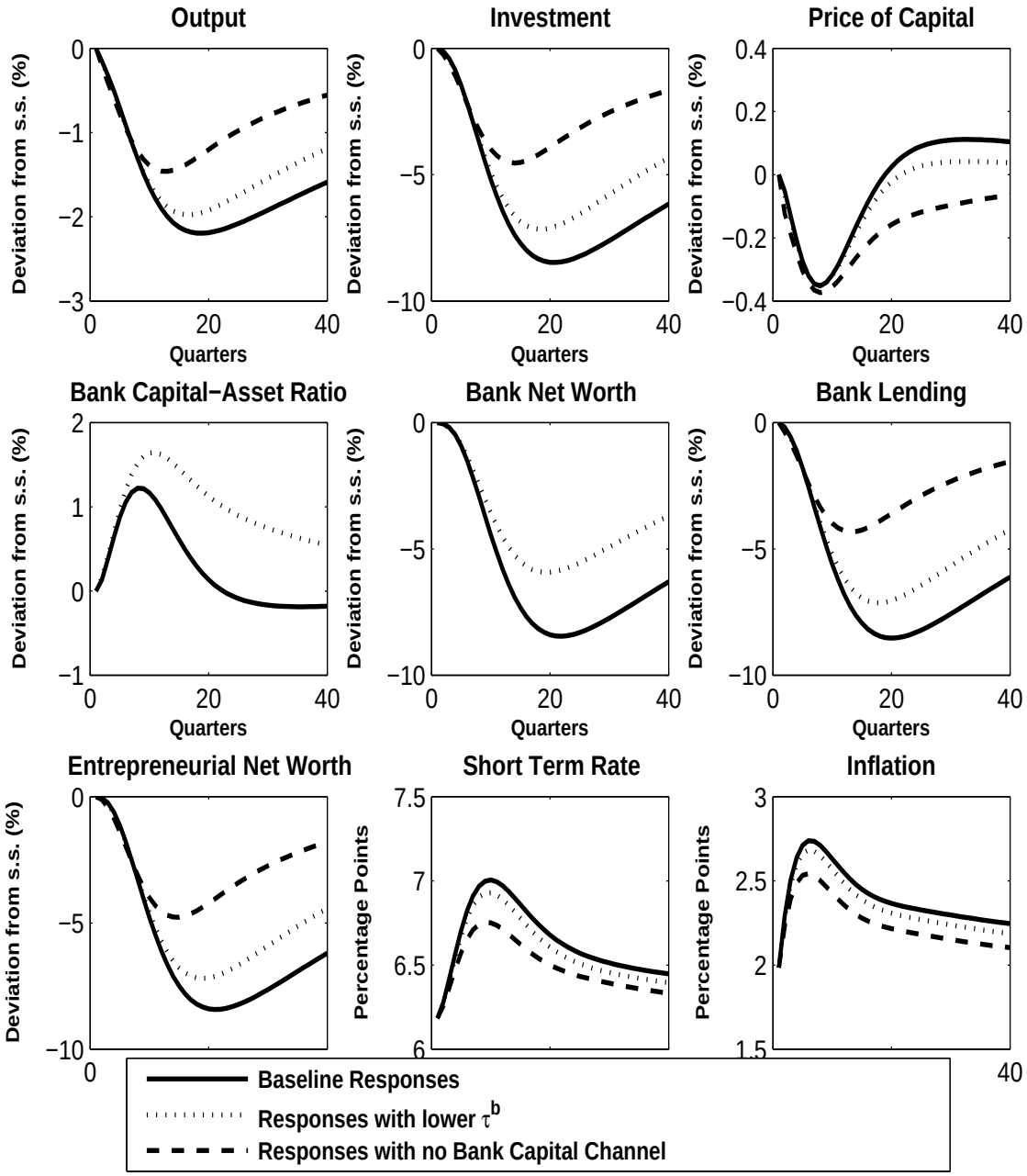
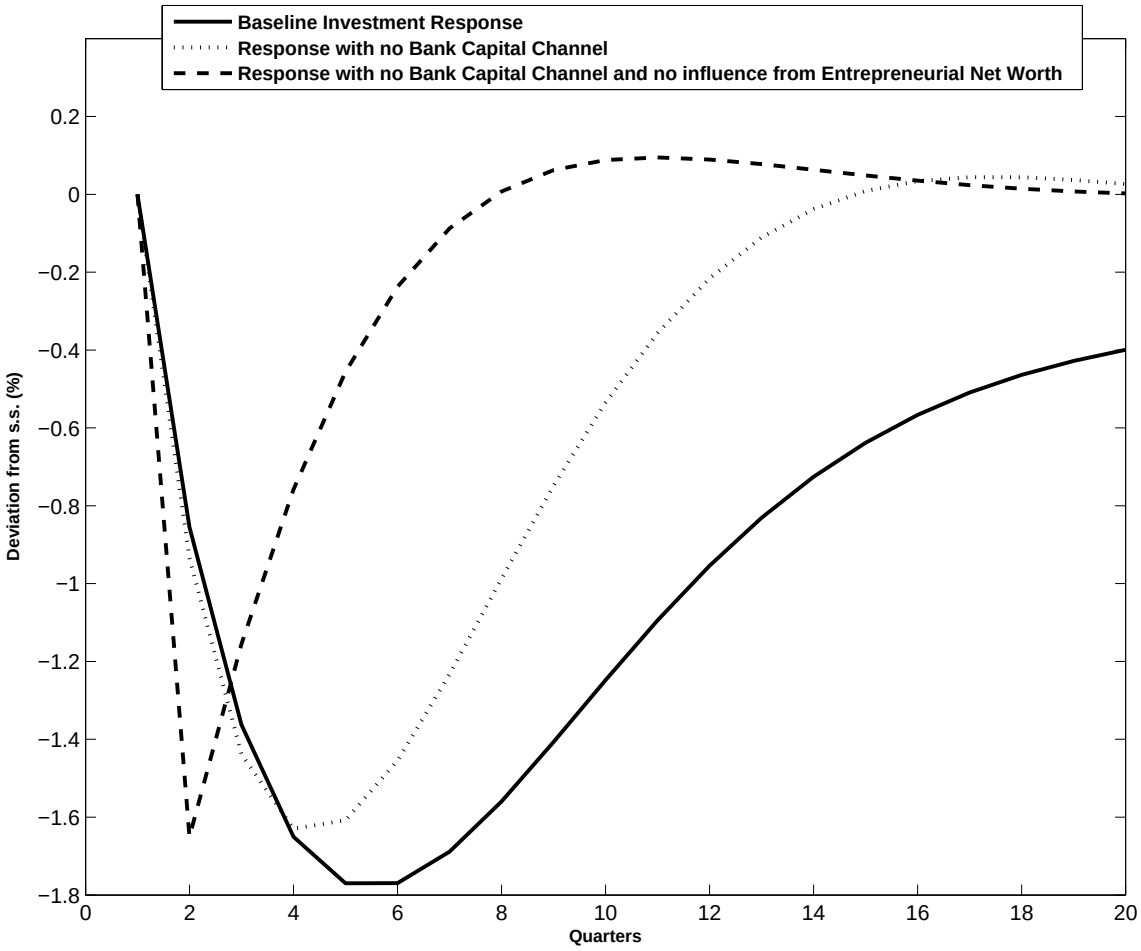
Figure 8. The Hump-shaped Response of Investment to a Monetary Policy Shock