

Bank Capital in a Quantitative Model with Financial Frictions ^{*}

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Abstract

Evidence suggests that banks, like firms, face financial frictions when raising funds, and that these frictions can have important macroeconomic effects. In this paper, we develop a quantitative, monetary business cycle model in which financial frictions affect the relationship between banks and their depositors, as well as the one between banks and firms. As a result, banking net worth -bank capital- and entrepreneurial net worth jointly determine aggregate investment and propagate economic shocks.

Our findings are as follows. First, the propagation mechanism from banking and entrepreneurial net worth creates important, hump-shaped responses of aggregate investment and output following shocks. A key element of this mechanism is the movement in the capital-asset ratio of banks, which is market-determined and follows a counter-cyclical pattern; such a pattern is also present in the data. Second, the evolution of bank capital itself contributes importantly to this mechanism, increasing its persistence.

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1 Introduction

A large body of literature analyzing the quantitative importance of financial factors in business cycle models has recently emerged. One class of this literature originates in the contributions of Williamson (1987) and Bernanke and Gertler (1989) and is exemplified by Carlstrom and Fuerst (1997, 1998, 2001) and Bernanke et al. (1999). It emphasizes an information friction that affects the relationship between financial intermediaries (banks) and firms, and limits firms' access to external financing. In this framework, high net worth mitigates the friction and enhances a firm's ability to borrow. As a result, the evolution of aggregate, firm net worth becomes a key element in the propagation of shocks.¹

Underlying much of this literature is the hypothesis that banks themselves face no financial frictions, and that their ability to lend is unaffected by their balance sheet. This hypothesis is, however, inconsistent with the data. Schneider (2001) reports that smaller, regional US banks appear to be financially constrained relative to larger banks. Further, a large body of evidence reports that poorly-capitalized banks (or relatively illiquid ones) have limited lending flexibility, and that these limitations have important macroeconomic consequences.² On the pricing side, Hubbard et al. (2002) report that banks' capitalization affect the rate at which their clients borrow. A natural interpretation of this evidence is that banks face financial frictions when raising loanable funds and that high levels of bank net worth -bank capital- mitigates these frictions. In turn, the evidence that such market imperfections may have important macroeconomic effects implies that they should inform the development of banking and business cycle models.

In this context, this paper presents a quantitative model that studies the link between the evolution of banking and entrepreneurial net worth, on the one hand, and the propagation of shocks, on the other. The framework we employ is a monetary, dynamic general equilibrium version of Holmstrom and Tirole (1997). The model features two moral hazard problems, the first one affecting the relationship between banks and their borrowers (entrepreneurs), and the second influencing the link between banks and their own source of funds (depositors). Moral hazard first arises because entrepreneurs, who produce the economy's capital good, can privately choose to undertake riskier projects in order to enjoy

¹A second class of literature emphasizes limited enforcement of contracts as the key financial-market imperfection (Kiyotaki and Moore, 1997; Cooley et al., 2004).

²This evidence originates from research on the 'capital crunch' of the early 1990s (Bernanke and Lown, 1991). It includes the results (Peek and Rosengren, 1997, 2000) that the decreases in the capitalization of Japanese banks resulting from the late 1980s crash in the Nikkei had negative effects on their lending activities in the United States, as well as on economic activity in sectors when these banks had a major presence. Additionally, Van den Heuvel (2002) reports that the output of a state whose banking system is poorly capitalized is more sensitive to monetary policy shocks. Finally, bank-level data (Kishan and Opiela, 2000; Kashyap and Stein, 2000) show that poorly capitalized banks (or relatively illiquid ones) reduce lending more significantly following monetary contractions.

private benefits. To mitigate this problem, banks require that entrepreneurs invest their own net worth in projects. The second source of moral hazard emerges because banks, to whom depositors delegate the monitoring of entrepreneurs, may not do so to avoid monitoring costs. In response, depositors demand that banks invest their own net worth -bank capital- in the financing of entrepreneurial projects.

We embed this framework within a monetary business cycle model that we calibrate to salient features of the US economy. Our findings are as follows. First, in the presence of these two moral hazard problems, the joint evolution of entrepreneurial and banking net worth becomes a powerful propagation mechanism for monetary policy and technology shocks, which have hump-shaped effects on aggregate investment and output. An essential component of this mechanism is the market-determined, counter-cyclical movements in banks' net worth-to-asset ratio, i.e. their capital-asset ratio. We show that this counter-cyclical pattern is also present in the data, which suggests this mechanism may have helped shaped recent movements in the observed capital-asset ratios of US banks. Second, we show that bank capital itself provides a sizeable, individual contribution to the mechanism, over and above that provided by entrepreneurial net worth. Specifically, we report that exogenous decreases in bank capital caused prolonged periods of economic slowdown and that the presence of bank capital increases the persistence in the effects of shocks.

Intuitively, the propagation mechanism works as follows. A monetary tightening, for example, raises the costs of the deposits that help finance investment projects. In response, the market requires that banks and firms finance a bigger share of investment projects with their own net worth: banks' capital-asset ratios must increase and entrepreneurial leverage must fall. At the aggregate level, banking and entrepreneurial net worth are comprised of retained earnings from preceding periods and are fixed. Bank lending must therefore decrease and aggregate investment falls. Lower investment depresses earnings of the entrepreneurial and banking sectors, thus reducing future levels of bank capital and entrepreneurial net worth. It is those declines that continue to propagate the shock over time, after the initial impulse to the interest rate has dissipated.

Our paper is related to others studying the link between bank capital and economic activity. Van den Heuvel (2004) analyzes the relation between bank capital, regulatory requirements, and monetary policy. In his model, bank capital is held as a buffer against the eventuality that regulatory requirements will bind in the future, as opposed to our economy, where bank capital serves to mitigate the financial friction faced by banks. Further, compared to Chen (2001), who also constructs a dynamic version of Holmstrom and Tirole (1997), the present paper studies quantitatively the link between bank capital and economic shocks, by embedding the double moral hazard environment in a standard monetary version of the neo-classical model.³

³Smith and Wang (2006) also consider bank capital within a dynamic framework; in their model,

The remainder of this paper is organized as follows. Section 2 describes the modeling framework and section 3 presents its calibration. Section 4 illustrates the propagation mechanism by which the evolution of entrepreneurial net worth and bank capital affects economic activity for prolonged periods. It also shows that a key component of this mechanism – the counter-cyclical movements in banks’ capital-asset ratios– is also present in the data. Section 5 finally illustrates that bank capital itself provides an important contribution to the mechanism, while section 6 concludes.

2 The Model

2.1 The environment

Time is discrete and one model period represents a quarter. There are three classes of 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, a rule relating nominal interest rates to economic activity and subjected to policy shocks summarizes the behavior of monetary authorities.

Households are infinitely-lived and risk averse. They rent their labour services and their stock of accumulated physical capital to firms producing final goods; they save by purchasing money and capital. Entrepreneurs and bankers are risk-neutral and each period face a (constant) probability of exiting the economy. Surviving entrepreneurs and bankers save by purchasing capital goods while those exiting the economy consume their accumulated wealth. Exiting agents are replaced by newly-born individuals: the population masses of each class of agents is thus constant.

There are two sectors of production. In the first, competitive firms produce the economy’s consumption (or final) good, using physical capital and labor. Production in that sector is subjected to aggregate technology shocks and is not affected by financial frictions. In the second sector, entrepreneurs produce the economy’s capital good using final goods. Their production function is affected by idiosyncratic risk but not by aggregate shocks. Further, production in the second sector is affected by two moral hazard problems.

The first such problem arises because entrepreneurs may privately choose to undertake projects with low expected returns (these projects provide them with private benefits). Monitoring entrepreneurs helps reduce this problem but does not eliminate it because the available monitoring technology is imperfect. As a result, entrepreneurs are compelled to invest their own net worth in projects, giving them the incentive to choose projects with high expected returns. The net worth of entrepreneurs thus becomes an important determinant of the extent to which external funds can be raised to finance projects.

bank capital serves as a buffer that allows banks to meet the liquidity requirements of long-lived financial relationships with firms. See also Stein (1998), Bolton and Freixas (2006), and Schneider (2001).

Banks act as delegated monitors for the households (the ultimate suppliers of loanable funds) because they alone possess the technology to monitor entrepreneurs. The second moral hazard problem arises because monitoring is costly and not publicly observable. To give banks the incentive to properly monitor the entrepreneurs, households require that banks engage their own net worth (i.e. the bank's *capital*) in financing projects. As a result, the net worth of banks -their capital- affects their ability to attract loanable funds. Weaving together the influence of the two sources of moral hazard implies that the joint evolution of entrepreneurial net worth and bank capital importantly affects aggregate lending and, ultimately, investment and economic activity.

2.2 Households

There is a continuum of households that maximize the expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t^h, l_t^h), \quad (1)$$

where β is the discount factor, c_t^h is the household's consumption and l_t^h its leisure.

A representative household starts period t with M_t units of money (liquid assets) and k_t^h units of physical capital. The current value of the aggregate technology and monetary shocks are revealed at the beginning of the period. During the period, the household rents this physical capital to final-good producers and augments his stock of capital through investment purchases

The nominal side of the economy is inspired by the recent 'limited participation' literature. This literature motivates the real effects of monetary shocks through frictions affecting households' financial transactions and it provides a natural framework to study the interaction of bank behavior and economic activity.⁴ In this context, we assume that the household keep a portion M_t^c of accumulated money balances as 'transaction cash' to make current-period purchases, whereas the remainder $M_t - M_t^c$ is allocated to deposits at financial intermediaries. The limited participation assumption is that this allocation of money between transaction cash and deposits is costly (in terms of time).

Each household is endowed with one unit of time, allocated to work effort h_t^h , leisure l_t^h , and the time costs of adjusting money balances $v_t = v(M_t^c, M_{t-1}^c)$.⁵ We thus have

$$h_t^h + l_t^h + v_t = 1. \quad (2)$$

⁴See for example Dotsey and Ireland (1995), Chari et al. (1995), Christiano and Gust (1999), Cooley and Quadrini (1999), and Andolfatto and Gomme (2003).

⁵These costs are interpreted as the time necessary to reevaluate and then rebalance nominal portfolios (Cooley and Quadrini, 1999).

The following cash-in-advance constraint applies to the household's purchases of consumption goods c_t^h and investment in new physical capital goods i_t^h :

$$c_t^h + q_t i_t^h \leq \frac{M_t^c}{P_t} + \frac{W_t}{P_t} h_t^h, \quad (3)$$

where q_t is the relative price of capital goods, W_t is the economy-wide wage and P_t is the aggregate price index.

The household directs the funds available for deposit, $M_t - M_t^c$ to a bank, which uses them to finance the investment projects of entrepreneurs. The (competitive) expected rate of return on these deposits is r_t^d (see section 2.5 below). However, idiosyncratic risk affects the bank's return from lending, and thus the household's return on its deposits, which is distributed at the end of the period. Specifically, with probability α , all the projects financed by the bank are successful and deposits are repaid in full. We denote this event by assigning the indicator variable s_t a value of 1. With probability $1 - \alpha$, all the bank's projects fail and the household gets zero return on its deposit. In addition to this income from deposits, the household also receives $r_t k_t^h$ from renting its physical capital to final-good producers. As a result, the evolution of the household's nominal balances is described by the following budget constraint:

$$\frac{M_{t+1}}{P_t} = s_t \frac{r_t^d}{\alpha} \left(\frac{M_t - M_t^c + X_t}{P_t} \right) + r_t k_t^h + \left(\frac{M_t^c}{P_t} + \frac{W_t}{P_t} h_t^h - c_t^h - q_t i_t^h \right). \quad (4)$$

In (4), the term third source of income (the term in brackets on the right-hand side represents any money left over from consumption and investment purchases in (3)). Further, X_t is a lump-sum money transfer from the monetary authority, related to its management of short-term interest rates (see below).⁶

Note that the constraints (3) and (4) imply that income received from physical capital holdings ($r_t k_t^h$) cannot be spent in the current period. Rather, this income must first be transformed into 'transaction cash', and only in future periods be used for purchases. This distortion represents a monetary-based tax on capital income which affects capital accumulation by households. In this context, a decrease in the interest rate r_t^d —following a monetary policy easing—reduces this tax and encourages capital accumulation (Carlstrom and Fuerst, 2001).

In addition, the standard capital accumulation equation applies, so that the stock of accumulated physical capital follows

$$k_{t+1}^h = i_t^h + (1 - \delta) k_t^h. \quad (5)$$

⁶The fact that monetary injections enter the economy exclusively through the financial sector creates an imbalance between liquidity in financial markets (where it is plentiful) and liquidity in goods' markets (where it is scarce). This imbalance is at the heart of the real effects of monetary policy in the 'limited participation' literature.

To obtain a tractable, quantitative solution, we abstract from heterogeneity at the level of households' deposit return. To do so, we assume that households can perfectly pool the idiosyncratic risk they face: since there is no aggregate risk in the production of capital goods, the return on bank deposits equals the expected return r_t^d for all households and the budget constrain (4) becomes:

$$\frac{M_{t+1}}{P_t} = r_t^d \left(\frac{M_t - M_t^c + X_t}{P_t} \right) + r_t k_t^h + \left(\frac{M_t^c}{P_t} + \frac{W_t}{P_t} h_t^h - c_t^h - q_t i_t^h \right). \quad (6)$$

Importantly, this renders households risk-neutral with respect to the financial contract detailed below.⁷

The household's intertemporal decision problem is then to choose a contingency plan

$$\{c_t^h, i_t^h, h_t^h, k_{t+1}^h, M_t^c, M_{t+1} | t \geq 0\}$$

that maximizes (1) subject to (5), (2), (3) and (4), given k_0^h , and M_0 .

2.3 Final good production

The final good is produced by competitive firms. These firms have access to a CRS production function whose inputs are physical capital and labor services from households, and is affected by aggregate technology shocks.⁸ The constant returns to scale imply that firm-level relations coincide with the economy-wide ones, which we present. Aggregate output of final goods Y_t is thus given by:

$$Y_t = z_t F(K_t, H_t), \quad (7)$$

where z_t is the technology shock, K_t is the aggregate stock of physical capital, and H_t represents aggregate labour input from households. The technology shock evolves according to the standard AR(1) process

$$z_t = \rho_z z_{t-1} + \epsilon_t^z, \quad \epsilon_t^z \sim (0, \sigma_z). \quad (8)$$

⁷Complete risk-pooling of deposits returns can be implemented by introducing insurance within households (Andolfatto, 1996; Cooley and Quadrini, 1999) or by assuming the presence of a capital mutual fund that directly pools households deposits (Carlstrom and Fuerst, 1997). Either interpretation is immaterial to the results we present. See Appendix B for details. Perfect risk-pooling does not make households indifferent to the two moral hazard problems, which have the potential to affect the *mean* return on deposits.

⁸To ensure that bankers and entrepreneurs can always pledge a non-zero amount of net worth in the financial contract, we also assume that the aggregate production function includes a small role for labor inputs from entrepreneurs and bankers, which entitles them to small wage payments every period (Carlstrom and Fuerst, 1997, 2001). These wages do not affect the model's dynamics and we ignore them hereafter. Alternatively, Chen (2001) assumes that entrepreneurs and bankers are entitled to modest levels of endowment each period.

We assume that final good producers pay workers in advance of production. To do so, they must borrow an amount equivalent to their wage bill from banks, at interest rate r_t^l . However, no asymmetric information problem affects the process by which these loans are obtained; net worth considerations are therefore not relevant for final good producers.⁹ The competitive nature of the sector implies that the usual first-order conditions apply to the choices of capital and labor:

$$r_t = z_t F_1(K_t, H_t); \quad (9)$$

$$w_t = \frac{z_t F_2(K_t, H_t)}{r_t^l}, \quad (10)$$

where $w_t = \frac{W_t}{P_t}$, the economy-wide real wage.

2.4 Capital good production

Each entrepreneur has access to a technology that transforms final good in capital goods. Specifically, an investment of i_t units of final goods yields a publicly observable return of Ri_t units of physical capital if the project succeeds, and zero units if it fails.

Entrepreneurs can influence the probability that their projects succeed, choosing to pursue a project with a low probability of success, for example, because it provides them private benefits. We adopt the formulation of Holmstrom and Tirole (1997) and Chen (2001) and define three possible projects, each carrying a different mix of public return and private benefits.¹⁰ First, the *good* project has a high probability of success (α^g) and zero private benefits. Second, the *low private benefit* project has a lower probability of success $\alpha^b < \alpha^g$ and provides to the entrepreneur private benefits proportional to the investment size ($b i_t$). Finally, the *high private benefit* project also has the low probability of success α^b and provides high private benefits $B i_t$, with $B > b$. Note that entrepreneurs would always choose this project over the second one, if not monitored by their bank. The table below summarizes the characteristics of the three projects.

Projects available to the entrepreneur			
Project	<i>Good</i>	<i>Low Private Benefit</i>	<i>High Private Benefit</i>
Private benefits	0	$b i_t$	$B i_t$
Probability of success	α^g	α^b	α^b

Banks have access to a monitoring technology that can detect, at a cost μi_t in finals

⁹These loans can be interpreted as the ‘working capital’ of big firms (Christiano and Gust, 1999; Cooley and Quadrini, 1999).

¹⁰Three projects is necessary to analyze imperfect bank monitoring.

goods, whether an entrepreneur has undertaken the high private benefit project.¹¹ Monitored entrepreneurs thus do not choose this project. However, the monitoring technology is imperfect and cannot distinguish the low private benefit project from the good one. Ensuring that entrepreneurs have an incentive to choose the good project is a crucial component of the financial contract discussed below.¹²

Bank monitoring is costly but not publicly observable, which creates a second moral hazard problem, affecting the relationship between banks and their depositors (the households). As a consequence, households prefer to entrust their deposits with well-capitalized banks (banks with high net worth) because these banks have a strong incentive –protect their own net worth– to properly monitor entrepreneurs.

The returns to the projects funded by each bank are perfectly correlated (either all funded projects succeed, or all fail). Assuming perfect correlation in banks’ returns from lending makes the solution of the model tractable, but could be relaxed at the cost of added complexity. The mechanism described in the present paper remains as long as banks are not able to completely diversify away the risk in their lending portfolio.¹³

2.5 External Financing

Entrepreneurs producing the economy’s capital goods are the first type of agents requiring external financing. This first type of external financing is undertaken in a context of the asymmetric information problem described above. Second, final-good producers require financing to cover their wage bill (their “working capital”). This external financing is conducted without any financial frictions.

Financing entrepreneurs

An entrepreneur with net worth n_t undertaking a project of size $i_t > n_t$ needs external financing worth $l_t^d = i_t - n_t$. The bank provides this financing using deposits it collects

¹¹Bank monitoring is interpreted as the inspection of cash flows and balance sheets, or the verification that firms conform with loan covenants (Holmstrom and Tirole, 1997). This is different from the interpretation given to monitoring in the costly state verification (CSV) literature, where it is associated with bankruptcy-related activities.

¹²Public returns and private benefits are constrained to ensure that a situation where entrepreneurs choose the good project represents the socially preferable outcome. To this end, the following is verified in steady state

$$q\alpha^g R - (1 + \mu) > 0 > q\alpha^b R + B - (1 + \mu).$$

The left-hand side of the equation stated that the good project, net of monitoring costs, is economically viable (recall that q is the relative price of capital goods); by contrast, the right-hand side states that even after accounting for the private benefit it provides, the overall economic return from the high private benefit project is negative.

¹³Diamond (1984) and Williamson (1987) assume perfect diversification in a bank’s loan portfolio; as a result, banks monitor without holding capital. Ennis (2001) presents a model where banks may choose to diversify at a cost, and where large, diversified banks and small, non-diversified ones co-exist.

from the households (d_t) as well as its own net worth (capital) a_t . Including the costs of monitoring the project ($= \mu i_t$), the bank is thus able to lend an amount $l_t^s = a_t + d_t - \mu i_t$.

The (optimal) financial contract underlying this loan is structured as follows. We assume the presence of inter-period anonymity, which restricts the analysis to one-period contracts.¹⁴ Further, we concentrate on equilibria where all entrepreneurs choose to undertake the good project; α^g thus represents the probability of success of all projects and therefore the probability that all household deposits are repaid ($\alpha = \alpha^g$). In that context, the contract specifies (i) that the entrepreneur invests all available net worth n_t while the bank and the households put up the reminder $i_t - n_t$, (ii) how the project return Ri_t , if successful, is shared among the entrepreneur ($R_t^e > 0$), the bank ($R_t^b > 0$) and the households ($R_t^h > 0$), and (iii) that all three agents receive zero return if the project fails.

The contract determines an investment size i_t , contributions to the financing from the bank (a_t) and the households (d_t), and the sharing rule (R_t^e, R_t^b, R_t^h), in order to maximize the value of the expected return to the entrepreneur, subject to incentive, participation, and feasibility constraints:

$$\max_{\{i_t, a_t, d_t, R_t^e, R_t^b, R_t^h\}} q_t \alpha^g R_t^e i_t, \quad \text{subject to} \quad (11)$$

$$q_t \alpha^g R_t^e i_t \geq q_t \alpha^b R_t^e i_t + q_t b i_t; \quad (12)$$

$$q_t \alpha^g R_t^b i_t - \mu i_t \geq q_t \alpha^b R_t^b i_t; \quad (13)$$

$$q_t \alpha^g R_t^b i_t \geq r_t^a a_t; \quad (14)$$

$$q_t \alpha^g R_t^h i_t \geq r_t^d d_t; \quad (15)$$

$$a_t + d_t - \mu i_t \geq i_t - n_t; \quad (16)$$

$$R_t^e + R_t^b + R_t^h = R. \quad (17)$$

Equation (12) is the incentive compatibility of entrepreneurs. Recall that if banks monitor, entrepreneurs do not choose the high private benefit project. However, they still must be induced to choose the good project. Their expected return is therefore at least as high as the one they get (inclusive of private benefits) if the low private benefit project is undertaken. Equation (13) is the bank's incentive compatibility constraint, which must be satisfied in order for monitoring to occur. It states that the expected return to the bank, if monitoring, is at least as high (net of the monitoring costs) as the expected return if not monitoring (a situation in which entrepreneurs would choose the project with high private benefits and probability of success α^b). Next, equations (14) and

¹⁴This follows Carlstrom and Fuerst (1997) and Bernanke et al. (1999). General-equilibrium environments modeling dynamic contracting are found in Gertler (1992), Smith and Wang (2006), and Cooley et al. (2004).

(15) are the participation constraints of the bank and the households, respectively. These constraints state that the funds engaged (net worth a_t for the bank and deposits d_t for the households) earn a return sufficient to cover the (market-determined) required returns on bank net worth r_t^a and deposits r_t^d . Finally, equation (16) indicates that the bank's loanable funds is sufficient to cover the entrepreneurs's financing needs and equation (17) states that the shares promised to the three different agents add up to the total expected return.

In equilibrium, (12) and (13) hold with equality, so that with (17) we have:

$$R_t^e = \frac{b}{\Delta\alpha}; \quad (18)$$

$$R_t^b = \frac{\mu}{q_t\Delta\alpha}; \quad (19)$$

$$R_t^h = R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t\Delta\alpha}; \quad (20)$$

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

Note from (18) and (19) that the shares allocated to the entrepreneur and the banker are determined by the severity of the moral hazard problem that characterizes their decisions. In economies where the private benefit b or the monitoring costs μ is higher, the project share allocated to the entrepreneur (or the bank) needs to increase. In turn, (20) shows that the per-unit share of project return that can be credibly promised to households as payments for their deposits is limited by the two moral hazard problems: if either of the two worsens, the maximal payment to households decreases.

Introducing (20) in the participation constraint of households (15) holding with equality leads to the following:

$$r_t^d d_t = q_t \alpha^g \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right) i_t, \quad (21)$$

whereas eliminating d_t from (21) using (16), and dividing by the project size i_t yields

$$r_t^d \left[(1 + \mu) - \frac{a_t}{i_t} - \frac{n_t}{i_t} \right] = q_t \alpha^g \left(R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right). \quad (22)$$

Equation (22) illustrates the mechanism by which monetary policy shocks affect the economy. A monetary tightening increase r_t^d , the market rate on deposits, but does not affect the per-unit share of project return that can be promised to households (the right-hand side of (22)). The increase in r_t^d must therefore be compensated by a reduced contribution of households' funds to the financing of a given-size project, i.e. by an increase in the relative contributions of bank net worth (a_t/i_t) and entrepreneurial net worth (n_t/i_t). At the aggregate level, however, bank net worth and entrepreneurial net worth

do not respond much contemporaneously to the shock, so that the project size i_t must decrease.

The last step in solving the contract simply solves for i_t in (22):

$$i_t = \frac{n_t + a_t}{G_t}, \quad (23)$$

where $1/G_t$ is the leverage over the net worth of the entrepreneur and the bank that the financial contract has achieved. Note that G_t depends only on parameters and economy-wide variables:

$$G_t = 1 + \mu - \frac{q_t \alpha^g}{r_t^d} \left(R - \frac{b}{\Delta \alpha} - \frac{\mu}{\Delta \alpha q_t} \right). \quad (24)$$

In equilibrium, i_t is positive, so G_t must be positive (since a_t and n_t are both > 0).

Expression (23) illustrates that the project size an entrepreneur can undertake depends on its net worth n_t as well as the capital a_t his bank is pledging towards the project. This translates into an expected output of new capital of $i^s(n_t, a_t; G_t) = \alpha^g R i_t$ which can be aggregated across all projects and interpreted as the supply curve for investment good (see below). Note that since $\frac{\partial G_t}{\partial q_t} = -\frac{\alpha^g (R - b/\Delta \alpha)}{r_t^d} < 0$, this supply curve is upward sloping. Further, (23) shows that increases in a_t or n_t shift this supply curve to the right, whereas the intuition shows that increases in r_t^d shift the curve to the left.¹⁵

Finally, define the ratio of the bank's net worth (or capital) to its assets as follows:

$$\kappa_t = \frac{a_t}{(1 + \mu)i_t - n_t}. \quad (25)$$

where by (16) $(1 + \mu)i_t - n_t = a_t + d_t$.

Financing final-good producers

Final good producers also require external financing, to cover their wage bill $w_t H_t$. However, there are no problem of asymmetric information involved in this and as a result, the net worth position of the financial intermediaries conducting this financing is not relevant.

We assume, without loss of generality, that there are two types of financial intermediaries. First, banks as described above lend to entrepreneurs and use their monitoring technology to limit the moral hazard affecting production in that sector. Second, banking agents costlessly intermediate funds between households and final good producers. As there are no information friction in involved in this transfers, banking agents do not net worth. Further, because their technology is costless, competition implies these agents

¹⁵The demand for capital good is defined by the first-order condition of the household problem with respect to k_{t+1}^h .

make zero profits.¹⁶

Note that each financial intermediary must offer households the same rate of return on deposits for the two types of lending to coexist in equilibrium. Further, because the second type of lending is costless, the equilibrium lending rate charge on this type of financing (r_t^l) equals the required rate on household deposits r_t^d . Finally, in the aggregate, funds utilized by both types of financial intermediaries must equal those directed by households towards financial markets.

2.6 Entrepreneurs and Bankers

Entrepreneurs are risk neutral. At the beginning of each period, a fraction $1 - \tau^e$ of the entrepreneurs receive the signal to exit the economy at the end of the period's activities; τ^e thus represents the probability of survival of an individual entrepreneur. Newborn entrepreneurs replace those that exit, so that their mass in the economy's population remains constant and equal to η^e .¹⁷ Their preferences are described by the following expected lifetime utility:

$$E_0 \sum_{t=0}^{\infty} (\beta \tau^e)^t c_t^e, \quad (26)$$

where $\beta \tau^e$ is the effective discount factor of entrepreneurs and c_t^e their consumption.

During the first part of the period, entrepreneurs accumulate net worth (internal funds) by renting their stock of physical capital k_t^e . This income, in addition to the value of the undepreciated capital, constitute the net worth (n_t) that entrepreneurs can pledge towards the financing of an investment project in the second part of the period:¹⁸

$$n_t = r_t k_t^e + q_t (1 - \delta) k_t^e, \quad (27)$$

where again r_t is the rental rate of capital in the final-good sector and q_t is the price of the capital good.

Bankers are agents endowed with a technology that enables them to monitor entrepreneurs. They arrange the financing of investment projects and act as delegated monitors

¹⁶Defining two types of financial intermediaries follows the formulation in Bernanke and Gertler (1985). As modeled, banking agents correspond to the financial intermediaries present in the standard limited participation literature (Cooley and Quadrini, 1999; Andolfatto and Gomme, 2003).

¹⁷Assuming that entrepreneurs have finite lives leads them, as an aggregate, to discount future more heavily than households and ensures they do not accumulate enough wealth to overcome the financial constraints. Alternatively, Carlstrom and Fuerst (1997) assume that entrepreneurs are infinitely-lived but discount the future more heavily than households do.

¹⁸Entering entrepreneurs have no accumulated physical capital but can still count on a non-zero stock of net worth since we assume that entrepreneurs also receive a very small wage.

for their depositors (the households). They are risk-neutral and also face a constant probability of exiting the economy $(1 - \tau^b)$.¹⁹ Their lifetime utility is

$$E_0 \sum_{t=0}^{\infty} (\beta \tau^b)^t c_t^b, \quad (28)$$

where c_t^b denotes bank consumption.

Bankers also accumulate net worth by renting their own holdings of physical capital (k_t^b) to final-good producers; bank net worth (bank capital) a_t is therefore

$$a_t = r_t k_t^b + q_t (1 - \delta) k_t^b. \quad (29)$$

In the second part of the period, each entrepreneur undertakes an investment project in which he invests all available net worth n_t and where the bank invests directly his own net worth a_t and indirectly the deposits d_t from its depositors. As described above, an entrepreneur whose project is successful receives a payment of $R_t^e i_t$ whereas his bank receives $R_t^b i_t$; unsuccessful projects have zero return.

At the end of the period, entrepreneurs and bankers associated with a successful project but having received the signal to exit the economy sell their return to buy and consume final (consumption) goods. Successful and surviving agents save their entire return, an optimal choice since they are risk neutral and the high (relative) return to internal funds induces them to postpone consumption. Unsuccessful agents neither consume nor save anything. These consumption and saving decisions are summarized as

$$c_t^j = \begin{cases} q_t R_t^j i_t & , \text{ if exiting and successful } (j = e, b) \\ 0 & , \text{ otherwise.} \end{cases} \quad (30)$$

$$k_{t+1}^j = \begin{cases} R_t^j i_t & , \text{ if surviving and successful } (j = e, b) \\ 0 & , \text{ otherwise.} \end{cases} \quad (31)$$

2.7 Aggregation

We denote most aggregate (economy-wide) variables by uppercase letters. The distribution of net worth and bank capital across agents in the economy has no effects on aggregate investment, as a result of the linear specifications in the production function for capital goods, the private benefits, and the monitoring costs. In this context, aggregate investment I_t is obtained by summing up the individual investment projects described in (23):

$$I_t = \frac{N_t + A_t}{G_t}, \quad (32)$$

¹⁹As is the case for entrepreneurs, exiting bankers are replaced by new ones at the beginning of the following period, so that their fraction of the economy's population remains fixed at η^b .

where N_t and A_t denote the aggregate levels of entrepreneurial net worth and bank net worth, respectively (G_t was defined in equation (24)). This represents the supply curve for new capital goods in the economy. As was the case for the individual relation, a fall in either A_t or N_t shifts this curve to the left and, all things equal, decreases aggregate investment I_t .

Moreover, the ratio of bank net worth to bank assets, defined in (25), can be aggregated to yield the following economy-wide measure:

$$\kappa_t = \frac{A_t}{(1 + \mu)I_t - N_t}, \quad (33)$$

while the economy-wide equivalent to the participation constrain of banks (14) now can be used to define the equilibrium return on bank net worth:

$$r_t^a = \frac{q_t \alpha^g R_t^b I_t}{A_t}. \quad (34)$$

Aggregate levels of holdings of physical capital are defined as:

$$K_t^e = \eta^e k_t^e; \quad K_t^b = \eta^b k_t^b. \quad (35)$$

Further, the aggregate levels of entrepreneurial N_t and bank net worth A_t , as well as holdings of physical capital next period (K_{t+1}^e and K_{t+1}^b) are found by summing up (27), (29), and (31) across all individual entrepreneurs and bankers:

$$N_t = (r_t + q_t(1 - \delta)) K_t^e; \quad (36)$$

$$A_t = (r_t + q_t(1 - \delta)) K_t^b; \quad (37)$$

$$K_{t+1}^e = \tau^e \alpha^g R_t^e I_t; \quad (38)$$

$$K_{t+1}^b = \tau^b \alpha^g R_t^b I_t. \quad (39)$$

Combining (32) to (36)-(39) yields the following law of motion for N_{t+1} and A_{t+1} :

$$N_{t+1} = \left(r_{t+1}^k + q_{t+1}(1 - \delta) \right) \tau^e \alpha^g R_t^e \left(\frac{A_t + N_t}{G_t} \right); \quad (40)$$

$$A_{t+1} = \left(r_{t+1}^k + q_{t+1}(1 - \delta) \right) \tau^b \alpha^g R_t^b \left(\frac{A_t + N_t}{G_t} \right). \quad (41)$$

Equations (40) and (41) illustrate the interrelated evolution of bank and entrepreneurial net worth. Aggregate bank net worth A_t , through its effect on aggregate investment (and hence on the retained earnings of the entrepreneurial sector), 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.

Finally, aggregating (30) across all entrepreneurs and banks yield the following expressions for aggregate consumption:

$$C_t^e = (1 - \tau^e)q_t\alpha^g R_t^e I_t(N_t, A_t); \quad (42)$$

$$C_t^b = (1 - \tau^b)q_t\alpha^g R_t^b I_t(N_t, A_t). \quad (43)$$

2.8 Monetary policy

Monetary authorities control the total supply of money in the economy. Denote beginning-of-period aggregate supply as \bar{M}_t and the injection of new money during the period as X_t , so that $\bar{M}_{t+1} = \bar{M}_t + X_t$. Following Christiano and Gust (1999), monetary policy is interpreted as choosing X_t so that the nominal deposit rate r_t^d targeted by monetary authorities obtains.

Consistent with Taylor (1993), we specify that the targeted rate reacts to deviations of inflation and aggregate output from their steady-state values:

$$\log(r_t^d/r^d) = \rho_y \log(Y_t/Y) + \rho_\pi \log(\pi_t/\pi) + \epsilon_t^{mp}, \quad (44)$$

where r^d , Y , and π are the steady-state values of r_t^d , Y_t , and π_t , respectively (π_t is the gross rate of increase in the price level), and ϵ_t^{mp} is a monetary policy shock (instances where monetary authorities depart for some time from their systematic policy) that follows

$$\epsilon_t^{mp} = \rho_{mp}\epsilon_{t-1}^{mp} + \xi_t, \quad (45)$$

with $0 \leq \rho_{mp} < 1$ and $\xi_t \sim (0, \sigma^{mp})$.

2.9 The competitive equilibrium

A competitive equilibrium for the economy consists of (i) decision rules for c_t^h , i_t^h , h_t^h , k_{t+1}^h , M_t^c , and M_{t+1} that solve the maximization problem of the household, (ii) decision rules for H_t and K_t that are consistent with the first-order conditions in (9)-(10), (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 (11)-(16), (iv) saving and consumption decision rules for entrepreneurs

and banks (30)-(31), and (v) the following market-clearing conditions:

$$H_t = \eta^h h_t^h; \quad K_t^h = \eta^h k_t^h; \quad (46)$$

$$K_t = K_t^h + K_t^e + K_t^b; \quad (47)$$

$$Y_t = C_t^h + C_t^e + C_t^b + (1 + \mu)I_t; \quad (48)$$

$$K_{t+1} = (1 - \delta)K_t + \alpha^g RI_t; \quad (49)$$

$$\frac{q_t \alpha^g R_t^h I_t}{r_t^d} + w_t H_t = \frac{M_t - M_t^x + X_t}{P_t}; \quad (50)$$

$$\bar{M}_t = M_t. \quad (51)$$

Figure 1 illustrates how different actions of the economy's agents unfold during a given period.

3 Calibration

The model is parameterized to ensure features of the non-stochastic steady state broadly match empirical counterparts. Whenever possible, we follow the calibration in the 'financial accelerator' literature (Carlstrom and Fuerst, 1997; Bernanke et al., 1999), to facilitate the comparison of our results with theirs.

Households preferences are given by

$$u(c_t^h, l_t^h) = \log(c_t^h) + \chi \log(l_t^h). \quad (52)$$

The weight on leisure χ is set to 1.9, which ensures that steady-state work effort by households is 30% of available time. One model period corresponds to a quarter so that the discount factor β is set at 0.99 (an average, annualized real rate of return on deposits of 4%). The portfolio adjustment costs v_t take the form

$$v_t(M_t^c, M_{t-1}^c) = \frac{\phi}{2} \left(\frac{M_t^c}{M_{t-1}^c} - \pi \right)^2, \quad (53)$$

where π is the steady-state growth of inflation. Adjustment costs are zero in steady-state and we set ϕ to 10 (Christiano and Gust, 1999).²⁰

The production technology in the final good sector is assumed to take the Cobb-Douglas form

$$Y_t = z_t K_t^{\theta_k} H_t^{\theta_h}, \quad (54)$$

²⁰The costs are small in an economic sense. To show this, measure the variance of M_{t+1}^c/M_t^c that would obtain if changes are costless ($\phi = 0$). Express this variance in terms of steady-state hours to represent the economic costs of the portfolio changes agents would like to, but cannot implement. In our simulations, these costs are very small.

Table 1: Baseline Parameter Calibration

Household Preferences						
χ	ϕ	β	δ			
1.9	15.0	0.99	0.02			
Final Good Production						
θ_k	θ_h	θ_e	θ_b	ρ_z	σ_z	
0.36	0.6399	$5 \cdot 10^{-5}$	$5 \cdot 10^{-5}$	0.95	0.01	
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	

where recall that the technology shock z_t , follows the AR(1) process

$$z_t = \rho_z z_{t-1} + \epsilon_t^z, \quad \epsilon_t^z \sim (0, \sigma^z). \quad (55)$$

We set θ_k to 0.36 and θ_h to 0.64. The autocorrelation parameter ρ_z is 0.95 while σ^z , the standard deviation of the innovations to z_t , is fixed at 0.01.²¹

Monetary policy takes the form of a Taylor (1993) rule, so that $\rho_\pi = 1.5$ and $\rho_y = 0.5$. The average rate of money growth (and thus the steady-state inflation rate) is set at 5 percent on an annualized basis, a value close to post-war averages in many industrialized countries. The autocorrelation of monetary policy shocks ρ_{mp} is set to 0.25 and its standard σ^{mp} to 0.01.

The parameters that remain to be calibrated (α^g , α^b , b , R , μ , τ^e , τ^b) are closely linked to the production of capital goods and the financial relationship linking entrepreneurs to banks and households. We set α^g to 0.9903, so that the (quarterly) failure rate of entrepreneurs is 0.97%, as in Carlstrom and Fuerst (1997). We set the remaining parameters in order for the steady-state properties of the model to display the following characteristics: 1) a ratio of bank net worth to assets (the model equivalent to capital-asset ratios of banks,

²¹Recall that a very small wage is given to entrepreneurs and banks, to make sure that they always have non-zero net worth. Doing so requires that their work is valued by the production function. We set the Coob-Douglas parameters for entrepreneurial and bank work very low ($10e - 6$) so they do not affect our quantitative results.

denoted κ) of 14 percent, the 2002 average risk-weighted, capital-asset ratio of US 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), as reported by Berger (2003) for US banks in the late 1990s; and 5) a ratio of aggregate investment to output of 0.2. Table 1 illustrates the numerical values of the parameter that emerge from the calibration. In particular, the parameter governing the importance of banks' monitoring costs, μ , is equal to 0.025. Once parameter values are determined, an approximate solution to the model's dynamics is found by linearizing all relevant equations around the steady state using the methodology of King and Watson (2002).

4 The Transmission of Shocks

This section analyzes the manner by which shocks to monetary policy and to technology are transmitted in our economy. Most noteworthy, it shows that the evolution of entrepreneurial and banking net worth serve to propagate the effects of the initial shock into subsequent periods. Further, the ratio of bank net worth to lending evolves in a counter-cyclical manner with respect to aggregate output, a pattern that replicates available evidence.

4.1 Monetary policy

Figure 2 presents the economy's response to a monetary tightening, i.e. a transitory, exogenous increase in r_t^d . This increase has both demand-side and supply-side effects on the market for new capital goods. On the demand side, the rise in r_t^d discourages capital accumulation, because it represents an increase in the (monetary-based) taxation of capital income discussed in section 2.2. As a result, the demand for new capital goods shifts to the left.

On the supply side, the monetary tightening represents a shift to the left of the supply curve of new capital goods. The intuition behind this shift is as follows. Recall equation (22), that arose from the financial contract linking banks, entrepreneurs and depositors; expressed with economy-wide variable, this equation reads

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

The far-right side of the expression re-states that the per-unit share of project return that can be paid to households for their deposits is limited by the double moral hazard: in particular, that share does not change when r_t^d increases. To compensate for that increase,

the left-hand side of the expression makes clear that reducing the reliance on deposits for financing a given-size project is the only option. Said otherwise, the increase in r_t^d worsens the moral hazard problem affecting the relationship between banks and households. Depositors now need to be better remunerated for their deposits and it becomes harder to satisfy their participation constraint while keeping the contract incentive-compatible.

Banks and entrepreneurs must therefore fill in the gap and invest more of their own net worth in the financing of each project. As a result, the ratio of bank net worth to aggregate investment (A_t/I_t) increases on impact, while entrepreneurial leverage (I_t/N_t) decreases (see Figure 2). Note that there are no financial regulations in the economy: this (counter-cyclical) increase in the ratio of bank net worth to investment is market-determined and related to the double moral hazard problem.

The aggregate levels of net worth N_t and A_t , however, are largely predetermined and do not change much on impact.²² As a result, the adjustment is mostly borne by aggregate investment I_t , which decreases significantly on impact. The impact on q_t , the relative price of capital goods, is uncertain as both demand and supply has shifted to the left: Figure 2 shows that on impact, the demand shift dominates and the q_t decreases.

At the end of the impact period, the reduced level of aggregate investment depresses earnings for banks and entrepreneurs. Since entrepreneurial and bank net worth consists of past retained earnings (see (40) and (41)), the fall in investment leads to extended declines in the levels of entrepreneurial and bank net worth. These declines represent substantial, additional shifts to the left of the supply curve for new capital goods. These declines in net worth now serve to propagate the effects of the shock into future periods: further declines in aggregate investment obtain, so that investment follows a hump-shape pattern. Further, since the interest rate increase is transitory, the demand shift is gradually eliminated and the additional supply shifts dominate the movements in the price of capital, which overshoots and converges back to its steady state from above.

The events on the market for new capital goods also influence behavior in the other markets. The initial decrease in the price of new capital, and its overshooting in following periods, encourage households' expenditures on new capital in the immediate aftermath of the shock. As a result, household consumption first decreases sharply and then converges back to steady-state from above, in a reverse-hump shape pattern. This response, first described in Carlstrom and Fuerst (1997), also has important consequences on households' labor supply, which rises initially.²³

Finally, on the labor market, the demand declines because the rise in interest rates has increased the labor costs of final-good producers.²⁴ Initially, the rise in labor supply limits

²²They consist of accumulated retained earnings from past periods : recall equations (36) and (37).

²³The demand for leisure declines in step with the decrease in consumption.

²⁴Recall that final-good producers must borrow to pay their wage bill. A monetary tightening thus shifts the demand for labor to the left.

the overall decline of hours and thus the response of hours follows a hump-shaped pattern. Because of the importance of hours in the production function and the slow response of capital, this hump-shaped response of hours is mirrored in the response of output, whose peak response (a decline of 0.2%) occurs in the period after the shock first affects the economy.

4.2 Technology

Figure 3 next reports the effects of a negative technology shock on the economy. This shock decreases the productive capacities of the final-good producers and is expected to persist significantly longer than the monetary policy shock analyzed above.

The expectation of several periods of lowered productivity reduces the expected rental income from holding physical capital and thus desired investment purchases by households. As there are no significant current-period shifts in supply, the price of capital q_t decreases on impact.

Now consider again equation (22): note that a decrease in q_t has a similar impact to the increase in r_t^d analyzed above on the double moral hazard problem. Moral hazard thus worsens and to keep the contract incentive-compatible, banks and entrepreneurs must again invest more of their own net worth in the financing of each project. As a result, the ratio of bank net worth to aggregate investment A_t/I_t increases on impact, while entrepreneurial leverage I_t/N_t decreases. With A_t and N_t largely pre-determined, the adjustment is borne by aggregate investment I_t , which declines significantly. Reduced aggregate investment depresses earnings and thus future net worth levels, which help propagate the shock in the future. As a result, investment declines for several periods before bottoming out. The important impact of technology on the productive capacities of the economy, as well as the higher persistence of the shock, means that the effects on investment are more significant than those of the monetary policy shock analyzed above.

As was the case following the monetary policy shock, the path of the price of capital –decreasing than overshooting above steady-state and converging from above– imparts a reverse hump-shape pattern to household consumption, as well as hump-shape patterns to the responses of output and household hours, which bottom out 3 periods after the initial shock.

The adverse technology shock also produces upward pressures on inflation. Considering the rule (44) followed by monetary authorities, this implies that nominal interest rates must rise to combat these pressures and limit the rise in inflation. Monetary authorities thus follow a tight monetary policy during the period where the adverse technology shock affects the economy, with targets interest rates being relatively high. Such a policy thus adds a second source of negative pressures on the economy and worsens the effects of the shock on output and investment.

4.3 Cyclical Properties of Banks' Capital-Asset Ratio

Figure 2 and 3 show that net-worth-to-asset ratio of banks is high when economic activity expands, and low when activity is slow. Recall that there are no regulatory capital requirements for banks in our model; these counter-cyclical movements are therefore market-generated, a product of the discipline imposed on banks by the financial contract and the presence of the two moral hazard problems.

The natural data counterpart to the model's net-worth-to-asset ratio is the capital-asset ratio of a banking system, as measured by the Bureau of International Settlements (BIS). Are the business cycle patterns of these two ratios comparable? If so, it might provide indirect evidence that market discipline affects banks' decisions on lending and capitalization. Such evidence would then provide support for the updated Basle Accord on capital adequacy requirements, which aims to facilitate the exercise of market discipline over banks through harmonized measurements and increased disclosure.

A comparison between the evidence from the US banking system and the model's implications for the banks' capital-asset ratios is presented in Table 2. The table presents the relative volatility of several economic variables, as well as the correlation structure linking the aggregate capital-asset ratio of the banking system to economic activity.

First, we document the facts. Bank capital-asset ratios are measured as the sum of *tier1* and *tier2* capital, over risk-weighted assets.²⁵ Panel A of the table shows that bank capital-asset ratios in the United States are one-third as volatile as output, while investment and bank lending are just over four times as volatile. Further, capital-asset ratios are persistent, with one-step and two-step autocorrelations of 0.9 and 0.8, respectively. Finally, the table shows that capital-asset ratios are countercyclical with respect to output, investment, and bank lending. These negative correlations extend to various leads and lags. Overall, the key message to take from the table is that capital-asset ratios, although not very volatile, are very persistent and negatively related to measures of bank lending and general economic activity.²⁶

The behavior of US banks, and therefore the movements in capital-asset ratios, probably reflects the influence of both regulatory requirements and market discipline. One can conjecture that adding regulatory requirements to market discipline makes capital-asset ratios more persistent and less volatile, the prospect of hitting regulatory floors inciting banks to limit movements.

In this context, the results in Panel B of Table 2 are instructive and can be interpreted

²⁵*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 weight is 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. The data we present are averages for all US banks and are from the BIS.

²⁶These facts are naturally related to the often-discussed procyclical nature of bank lending.

in a straightforward manner. Since only market discipline is at play in our model, the capital-asset ratio are more volatile and less persistent. Interestingly, however, the counter-cyclical behavior present in the data is replicated fairly well by the model, although the model's correlation between capital-asset ratios and output is too strong, and a lagging pattern between capital-asset ratios and economic activity is at odds with the data.

Overall, this exercise suggests that market discipline may have played an important, but not exclusive, role in shaping the evolution of bank capital and the capital-asset ratio of banks over the recent monetary history. Said otherwise, markets may have the capacity to provide discipline over the behavior of banks, as the 'Pillar 3' in the new Basle Accord assumes.²⁷ Deepening market discipline over banks could therefore increase the quantitative importance of the mechanism featured in this paper; doing so would lead to situations where bank lending and aggregate investment are more dependent on the health of the balance sheets in the banking and entrepreneurial sectors.

5 The Importance of Bank Capital

Section 4 has demonstrated that in our environment with two moral hazard problems, the joint evolution of entrepreneurial and bank net worth helps propagate shocks in future periods, after the initial effects of these shocks has dissipated. The present section analyzes the individual importance of the net worth of banks in this transmission mechanism. It shows that exogenous declines in bank net worth lead to prolonged economic slowdowns, and that the presence of bank net worth increases the persistence in the effects of shocks on the economy.

Overall, therefore, the presence of a moral hazard problem between banks and depositors, which compels banks to hold and invest their own net worth in investment projects, plays an important part in the propagation of economic shocks, over an above that played by entrepreneurial net worth.

5.1 A decrease in bank capital

Figure 4 describes the effects of an exogenous decrease in K_t^b , the stock of asset holdings in the banking sector. The decrease is sizeable (-10%) and could be interpreted as the failure of an important bank or as a decrease in the net worth of a country's banking sector, resulting from an important and unexpected depreciation of the local currency. The figure illustrates that the evolution of bank capital is important for economic activity and that exogenous decreases in its level can lead to prolonged economic slowdowns.

²⁷The proposed new Basle accords on capital requirements contain three 'pillars': minimum regulatory requirements, supervision, and market discipline. See Rochet (2004) for a review of the debate over the three pillars of the new Basle accord and a model in which the first and third of these pillars can interact.

Table 3. Cyclical Properties of the Capital-Asset Ratio

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}
<i>Panel A: US Economy</i>						
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
<i>Panel B: Model Economy</i>						
Banks' Capital-Asset Ratio	1.79	0.30	0.67	1.00	0.67	0.30
Investment	3.11	0.40	0.11	-0.30	-0.50	-0.58
GDP	1.00	0.20	-0.20	-0.65	-0.59	-0.50
Bank Lending	3.37	0.30	-0.05	-0.49	-0.57	-0.58

Note For the US economy, 1990:1-2005:1. 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). 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 the average, over 500 repetitions, of simulating the model for 100 quarters, filtering the simulated data, and computing the appropriate moments.

The decrease K_t^b has a direct repercussion on the net worth A_t of the banking sector, which decreases on impact. Following the logic of equation (32), this represents a shift to the left of the supply curve for new capital goods; as a result, the price of capital q_t increases and aggregate investment I_t declines by a sizeable amount (-1%). Since bank capital is now much scarcer at the aggregate level, its implicit return increases and the capital-asset ratio κ_t decreases: for a given-size project, participants in the financial contract economize on banks' contribution and more financing comes from the entrepreneurs' and depositors' contributions. As a result, entrepreneurial leverage $\frac{I_t}{N_t}$ decreases significantly.

In step with the intuition discussed in the preceding section, the decline in aggregate investment depresses earnings for the banking and entrepreneurial sectors. This translates into lower levels of entrepreneurial and bank net worth in future periods. It is those reduced net worth levels that continue to propagate the initial shock into future periods: aggregate investment, the price of capital and aggregate output only gradually return to steady state.

5.2 Bank capital in the transmission of shocks

An alternative measure of the individual contribution of banking net worth in the propagation of shocks is provided by Figure 5. The figure depicts the effects on the economy of the monetary tightening discussed above in Section 4.1 and illustrated by Figure 2.

The solid lines of Figure 5 represent the baseline case and thus simply reproduce those in Figure 2. The dashed lines in the figure illustrate the response of an economy where bank net worth (capital) A_t is maintained at its steady-state level by lump-sum transfers from the government. Shutting down the dynamics of A_t in this way enables us, by comparing the two sets of responses, to identify the individual contribution of bank capital in propagating the monetary tightening.

Figure 5 shows that bank capital increases the persistence in the effects of the shock. With the dynamics in A_t shut off, the initial response of output is -0.17% , with a half-life of 7 quarters; by contrast, in our baseline case with the dynamics of A_t governed by the financial contract, the response of output is of the same initial magnitude but the half-life is 9 quarters.²⁸ The longer half-life in the baseline economy represents the persistence that is added to the system by the evolution of bank capital. In the case of aggregate investment, the half-life of the shock is 9 quarters when bank capital does not react and 11 quarters in the baseline economy. Again, bank capital adds persistence to the response of the economy following the monetary tightening. Finally, note that the peak decline in investment is more important and occurs later in the baseline case (solid lines) than in the alternative case where bank capital is maintained at its steady-state levels (dashed lines).

These differentiated effects occur because the shift to the left in the supply curve for new capital goods (discussed above in section 4.1) is less pronounced when bank capital is constant. Figure 5 thus provides important evidence that the evolution of bank capital, governed by the moral hazard problem between banks and depositors, affects the transmission of shocks through our economy.

6 Conclusion

This paper presents a quantitative dynamic model that emphasizes the role of bank capital and entrepreneurial net worth in propagating shocks. The model features two moral hazard problems. The first arises because entrepreneurs can privately influence the probability of success of investment projects even if monitored. Banks thus require entrepreneurs to invest their own net worth in projects. The second problem occurs because bank monitoring is not publicly observable, which leads households to deposit funds only in banks that invest their own net worth in entrepreneurs' projects.

²⁸We follow Carlstrom and Fuerst (2001) in measuring persistence from the initial response of the economy following a shock.

As a result, entrepreneurial net worth and bank capital become key determinants of the propagation over time of shocks affecting the economy, even after their initial, direct impact has faded away. An important aspect of this propagation mechanism is that it generates market-determined, counter-cyclical movements in banks' capital-asset ratios, not unlike those observed in actual economies; this suggests that market discipline can exercise a powerful influence on bank behavior. Further, the evolution of bank capital itself contributes importantly to this mechanism, affecting the persistence and the amplitude of economic fluctuations following shocks.

This paper represents a first step in establishing a framework where the interaction of bank capital with economic fluctuations can be analyzed in a quantitative, DSGE model. A first direction for future research would be to enable the model to account for the sizable heterogeneity (in terms of size, capital position, or balance sheet composition) that is observed in the banking sector of most countries.²⁹ Tractability required that the present model abstract from such heterogeneity but important further insights and policy implications could potentially be gained from such work.

Further, the introduction of externalities, stemming from the role of banks' liabilities as means of payments, holds much promise. Enriching our framework in that direction would allow the model to study the role for government intervention in the banking sector, in response to large bank failures that impact on viability of the exchange mechanism.

²⁹This heterogeneity is documented, for the United States, in Ennis (2001b).

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Figure 1. Timing of Events

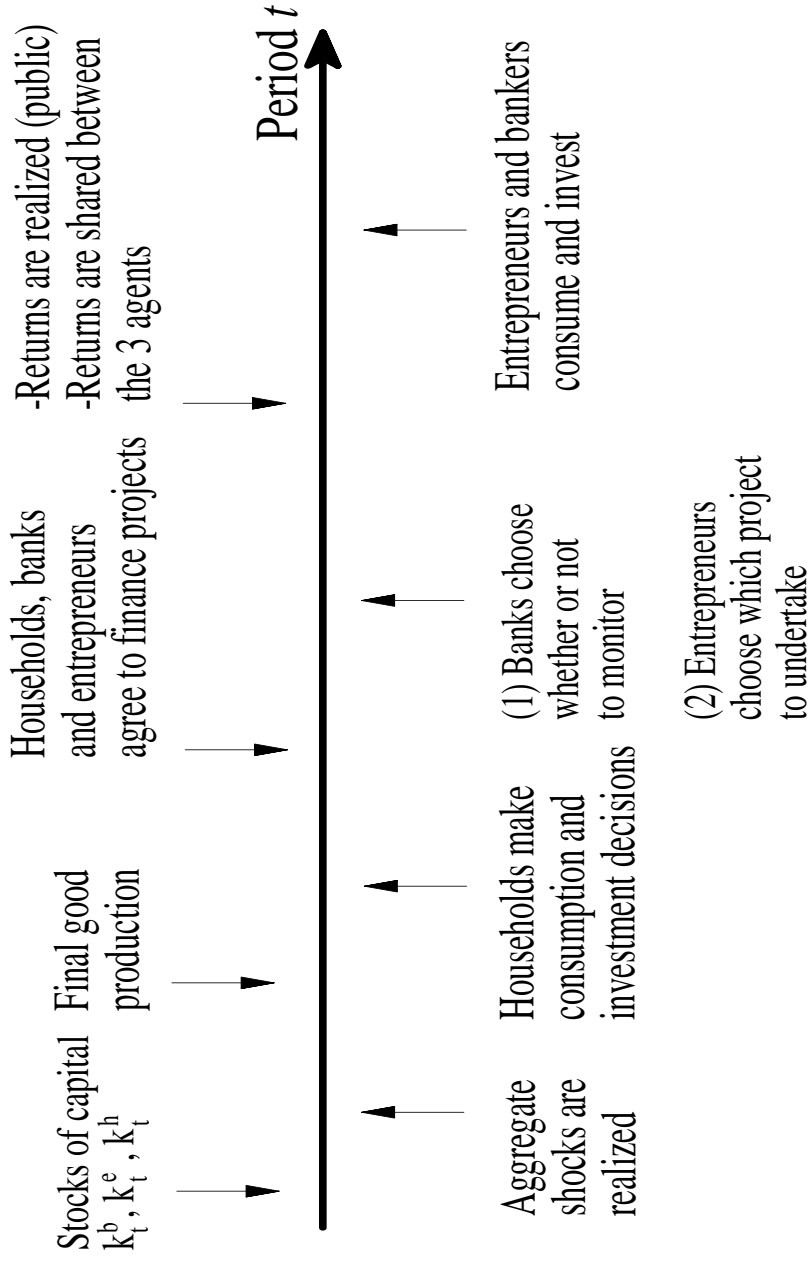


Figure 2. Monetary Policy Tightening

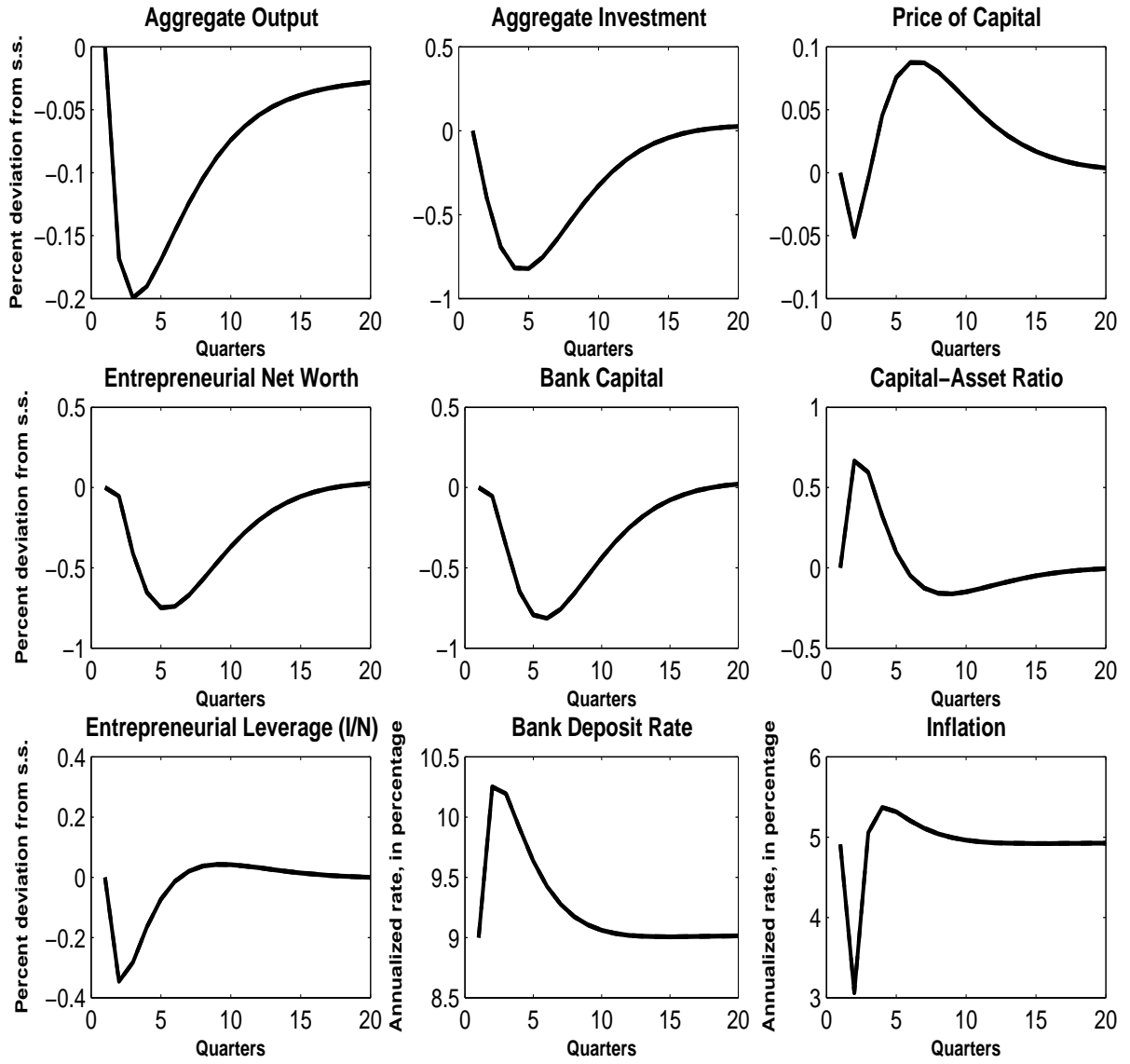


Figure 3. Adverse Technology Shock

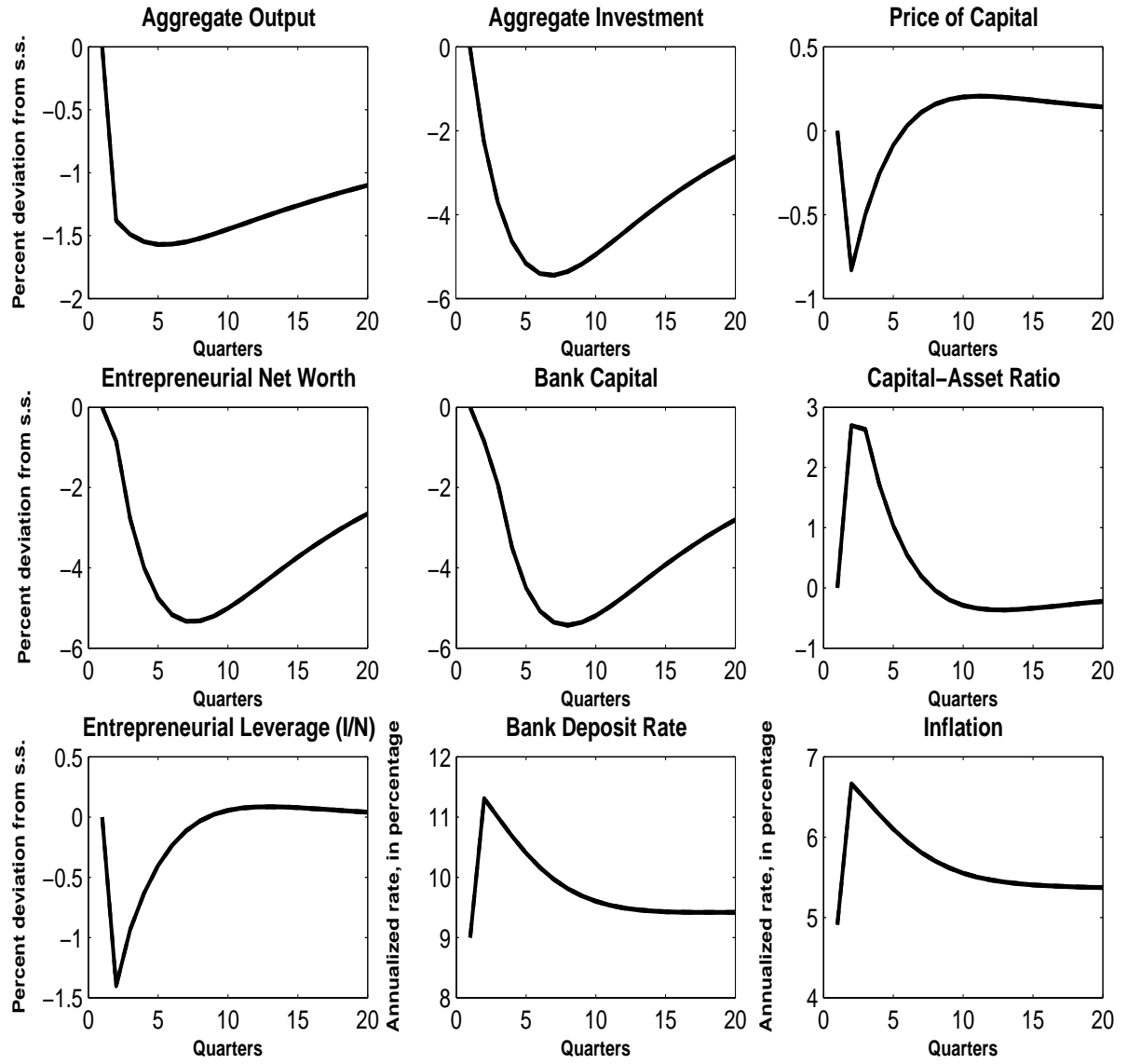


Figure 4. Exogenous Decrease in Bank Capital

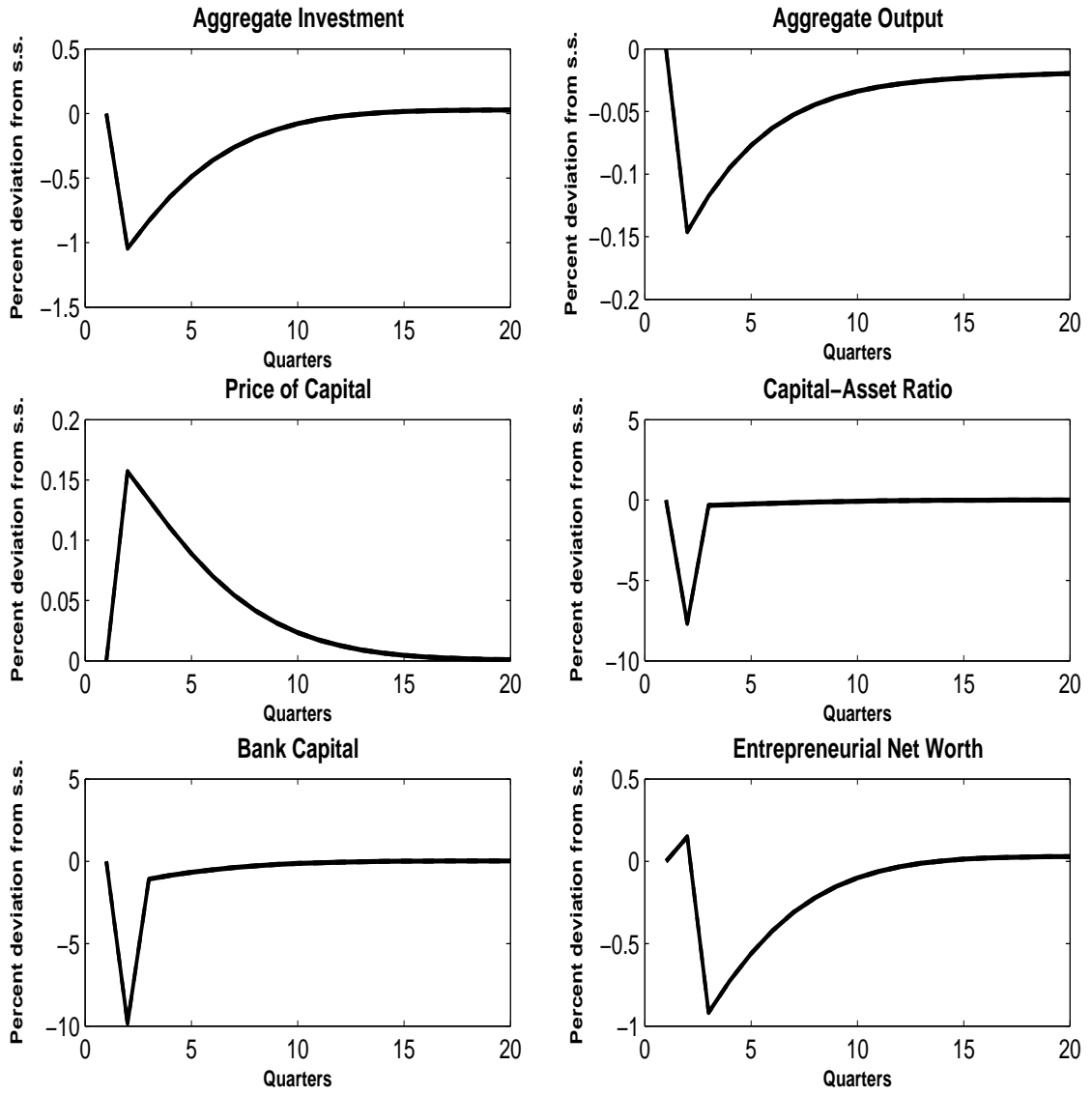
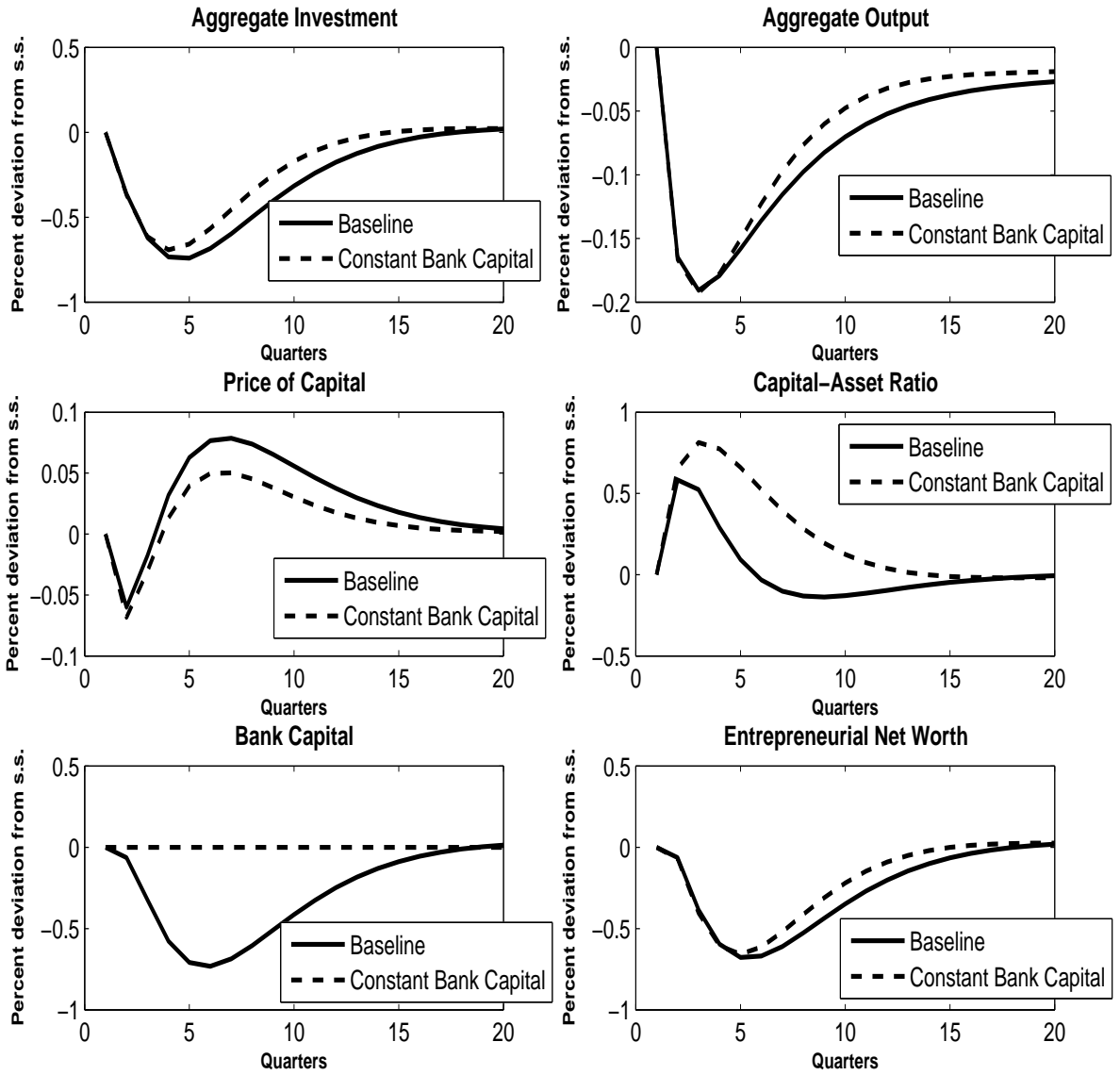


Figure 5. Bank Capital in the Transmission of a Monetary Tightening



Appendix A: Intra-Household Risk-Pooling of Deposit Risk

Following Andolfatto (1996) and Cooley and Quadrini (1999), we assume the existence of an (actuarially fair) insurance market that allows households to eliminate the idiosyncratic risk inherent to the financial contracts. Specifically, the household can purchase y_t real units of insurance, at the price j_t . These units are paid to the household in the event that he receives a zero return from his bank deposits. The budget constraint (4) can now be rewritten as follows:

$$\frac{M_{t+1}}{P_t} + j_t y_t = s_t \frac{r_t^d}{\alpha^g} \left(\frac{M_t - M_t^c + X_t}{P_t} \right) + r_t k_t^h + \left(\frac{M_t^c}{P_t} + \frac{W_t}{P_t} h_t^h - c_t^h - q_t i_t^h \right) + (1 - s_t) y_t; \quad (56)$$

where recall that s_t is an indicator function that takes a value of 1 if the bank deposits are repaid (no insurance payments) and a value of 0 if deposits have a zero return (insurance payments are made). Insurance premiums $j_t y_t$ are paid irrespective of events.

The first-order condition for the choice of y_t is the following:

$$j_t = E_t[1 - s_t] = 1 - \alpha^g, \quad (57)$$

which repeats the statement that the insurance market is actuarially fair. That feature, as well as the strict concavity of the utility function in consumption, implies that households will seek to remove any risk to their financial income flows. This requires that financial revenues (including net insurance revenues) when deposits bring zero returns should equal these revenues when deposits pay their promised returns (net of insurance premiums). We thus have:

$$y_t - j_t y_t = \frac{r_t^d}{\alpha^g} \left(\frac{M_t - M_t^c + X_t}{P_t} \right) - j_t y_t, \quad (58)$$

which simplifies to $y_t = \frac{r_t^d}{\alpha^g} \left(\frac{M_t - M_t^c + X_t}{P_t} \right)$.

Inserting this result back into (56) makes clear that the budget constraint is now similar to the one in a representative-agent economy with no idiosyncratic risk to household deposits:

$$\frac{M_{t+1}}{P_t} = r_t^d \left(\frac{M_t - M_t^c + X_t}{P_t} \right) + r_t k_t^h + \left(\frac{M_t^c}{P_t} + \frac{W_t}{P_t} h_t^h - c_t^h - q_t i_t^h \right). \quad (59)$$

as in (6) in the text.