

# Bank Capital, Agency Costs, and Monetary Policy \*

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## Abstract

Evidence suggests that banks, like firms, face financial frictions when raising funds. In this paper, we develop a quantitative, monetary business cycle model in which agency problems affect both the relationship between banks and firms as well as that linking banks to their depositors. As a result, bank capital and entrepreneurial net worth jointly determine aggregate investment, and help propagate shocks affecting the economy.

Our findings are as follows. First, we find that the effects of monetary policy shocks are dampened but more persistent in our environment, relative to an economy where the information friction facing banks is reduced or eliminated. Second, after documenting that the bank capital-asset ratio is countercyclical in the data, we show that our model, in which movements in the bank capital-asset ratio are market-determined, replicates that feature.

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# 1 Introduction

A large body of literature analyzing the quantitative importance of agency costs in otherwise standard business cycle models has recently emerged. Originating in the theoretical contributions of Williamson (1987) and Bernanke and Gertler (1989), this literature is exemplified by Carlstrom and Fuerst (1997, 1998, 2001) and Bernanke et al. (1999).<sup>1</sup> It features an information friction that affects the relationship between financial intermediaries (banks) and their borrowers (firms) and limits the ability of firms to obtain external financing. In such a context, the net worth of firms becomes an important element in the propagation of shocks because of its ability to mitigate the information friction.

However, evidence suggests that banks themselves are subject to financial frictions in raising loanable funds. Schneider (2001) reports that regional and rural US banks appear to be financially constrained relative to banks operating in urban centres. Further, a large body of evidence suggests that poorly-capitalized banks have limited lending flexibility, a fact consistent with the presence of financial frictions at the bank level.<sup>2</sup> Moreover, Hubbard et al. (2002) show that differences in the capital positions of banks affect the rate at which their clients can borrow. These facts imply that bank capital (bank net worth) might also contribute to the propagation of shocks and therefore that its evolution should be analyzed jointly with that of firm net worth.

This paper undertakes such an analysis. We develop a quantitative model that studies the link between the evolution of bank capital and entrepreneurial net worth, on the one hand, and monetary policy and economic activity, on the other. The framework we employ is a monetary, dynamic general equilibrium version of Holmstrom and Tirole (1997) that features *two* sources of moral hazard, 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). The first source of moral hazard arises because entrepreneurs, who produce the economy's capital good, can privately choose to undertake riskier projects in order to enjoy private benefits. To mitigate this problem, banks require entrepreneurs to invest their own net

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<sup>1</sup>Other contributions include Fuerst (1995) and Cooley and Nam (1998). The mechanism described in these papers is often labelled the 'financial accelerator'.

<sup>2</sup>See the discussions about the 'capital crunch' of the early 1990s (Bernanke and Lown, 1991), as well as the evidence (Peek and Rosengren, 1997, 2000) that shocks to the capital position of Japanese banks resulting from the late 1980s crash in the Nikkei had negative effects on their lending activities in the United States.

worth in the projects. The second source of moral hazard stems from the fact that banks, to whom depositors delegate the monitoring of entrepreneurs, may not do so in order to save on monitoring costs. In response, depositors demand that banks invest their own net worth, that is bank capital, in the financing of entrepreneurial projects.

We embed this framework within a standard monetary model that we calibrate to salient features of the US economy. Our findings are as follows. First, the presence of bank capital affects the economy's response to shocks. Specifically, the effects of monetary policy shocks are dampened and slightly more persistent in our environment, relative to an economy where the information friction facing banks is eliminated and, as a consequence, bank capital is not present. This is consistent with evidence that monetary policy contractions will depress lending and economic activity more significantly when bank capital is low.<sup>3</sup> In a related result, a sensitivity analysis reveals that varying the severity of this financial friction modifies significantly the impact of economic shocks. Second, after documenting that the capital-asset ratio is countercyclical in the data, we show that our model, where movements in this ratio are market-determined rather than originating from regulatory requirements, can replicate this feature.

Intuitively, the mechanism featured in the paper functions as follows. A contractionary monetary policy shock raises the opportunity cost of the external funds banks use to finance investment projects. In response, the market requires that banks and firms finance a bigger per-unit share of investment projects with their own net worth, i.e., bank capital-asset ratios must increase and entrepreneurial leverage must fall. Since bank capital and entrepreneurial net worth are predetermined (they are comprised of retained earnings from preceding periods), bank lending must decrease and thus aggregate investment must fall. In turn, lower aggregate investment depresses bank and entrepreneurs' earnings and thus reduces future bank capital and entrepreneurial net worth, whose declines continue to propagate the shock over time after the initial impulse to the interest rate has dissipated. Note that by contrast to the existing 'accelerator' literature, it is the joint evolution of entrepreneurial net worth and bank capital that affects how much external financing entrepreneurs can raise and thus the scale of their

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<sup>3</sup>Van den Heuvel (2002c) reports that the output of a state whose banking system is poorly capitalized is more sensitive to monetary policy shocks. Kishan and Opiela (2000) use bank-level data to show that poorly capitalized banks reduce lending more significantly following monetary contractions, whereas Kashyap and Stein (2000) report that banks holding more liquid securities can limit the reductions in lending following similar contractions.

investment projects. In the experiments where the financial friction facing banks is reduced, banks hold less capital (none if the friction is eliminated) and bank lending therefore relies relatively more on household deposits. In such circumstances, the increase in the price of these deposits that a contractionary shock causes leads to bigger adverse effects on investment and output.

Our paper is related to others studying the link between bank capital and economic activity. Van den Heuvel (2002a) analyzes the relation between bank capital, regulatory requirements, and monetary policy. In his model, bank capital is held as a buffer stock 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. Moreover, the production, savings, and monetary sides of the model in Van den Heuvel (2002a) are not fully developed whereas we present a detailed general-equilibrium economy. 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 monetary policy, by embedding the double moral hazard environment in a standard monetary version of the neo-classical model.<sup>4</sup>

The remainder of this paper is organized as follows. Section 2 describes the basic structure of the model. In order to focus the discussion on the financial contract linking banks, entrepreneurs, and households, we assume that households are risk-neutral and that only entrepreneurs require external financing. The model is then calibrated in Section 3. Section 4 describes and illustrates the channel by which shocks affect the economy through their impact on entrepreneurial net worth and bank capital. Section 5 extends the model, by introducing risk-aversion in household preferences as well requiring bank financing in both sectors (capital good and consumption good production) of the economy. It shows that the main qualitative features of the transmission channel discussed in Section 4 are not affected by these extensions. Section 6 presents our main findings. First the presence of bank capital affects the amplitude and the persistence of monetary policy shocks; second, the market-generated capital-asset ratio is countercyclical. Section 7 concludes.

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<sup>4</sup>Smith and Wang (2000) also consider bank capital within a dynamic framework; in their model, 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 (2000), Schneider (2001) and Berka and Zimmermann (2002).

## 2 The Model

### 2.1 The environment

A continuum of risk-neutral agents inhabits the economy. There are three classes of agents: households, entrepreneurs, and bankers, with population mass  $\eta^h$ ,  $\eta^e$ , and  $\eta^b$ , respectively, where  $\eta^h + \eta^e + \eta^b = 1$ . In addition, there is a monetary authority which conducts monetary policy by targeting interest rates.

There are two distinct sectors of production. In the first, many competitive firms produce the economy's final good, using a standard constant-returns-to-scale technology that employs physical capital and labour services as inputs. Production in this sector is not affected by any financial frictions.

In the second sector, entrepreneurs produce a capital good which will serve to augment the economy's stock of physical capital. In contrast to the situation in the first sector, the production environment in the capital good sector is characterized by two distinct sources of moral hazard, with the resulting agency problems limiting the extent to which entrepreneurs can receive external funding to finance their production. First, the technology available to entrepreneurs is characterized by idiosyncratic risk that is partially under the (private) control of the entrepreneur. Monitoring entrepreneurs is thus necessary to limit the riskiness of the projects they engage in. Second, the monitoring activities performed by the agents capable of undertaking them, the bankers, are themselves not publicly observable, creating a second source of moral hazard originating within the banking system. Moreover, a given bank cannot choose projects to finance in a manner that diversifies away the risk to its loan portfolio, thus implying that a bank can fail.

In order to limit the impact of these financial imperfections, households (the ultimate lenders in this economy) require that both entrepreneurial net worth and bank capital be invested in a project before they are induced to deposit their own money towards the funding of entrepreneurs' projects. The joint evolution of entrepreneurial net worth and bank capital thus become an important determinant in the reaction of the economy to the shocks affecting it.

Households are infinitely-lived; they save by holding physical capital and money. They then divide their money holdings between what they send to banking institutions and what they

keep as cash; a cash-in-advance constraint for consumption rationalizes their demand for that latter asset. They cannot monitor entrepreneurs or enforce financial contracts and therefore only indirectly lend to them, through their association with a bank that acts as delegated monitor. Bankers and entrepreneurs face a constant probability of exiting the economy; surviving individuals save by holding capital whereas those who receive the signal to exit the economy consume their accumulated wealth. Exiting entrepreneurs and bankers are replaced by newly born individuals, so that the population masses of the three classes of agents does not change. Figure 1 illustrates the timing of events that unfold each period in our artificial economy: next, we proceed to describe in greater detail these events, the optimizing behaviour of each type of agents and the connections between them.

## 2.2 Households

Each household enters period  $t$  with a stock  $M_t$  of money and a stock  $k_t^h$  of physical capital. The household is also endowed with one unit of time which is divided between leisure, work, and the time cost of adjusting the household's financial portfolio (see below). At the beginning of the period the current value of the aggregate technology and monetary shocks are revealed.

The household then separates into three different agents with specific tasks. The household *shopper* takes an amount  $M_t^c$  of the household's money balances and travels to the final goods market where it purchases the household's consumption ( $c_t^h$ ). The *financier* takes the remaining money  $M_t - M_t^c$ , which, along with  $X_t$  (the household's share of the period's monetary injection) he invests in bank deposits and thus indirectly in the financing of entrepreneurial projects. This investment is risky: entrepreneurial projects financed with the help of the household's funds could fail. In such a case, those funds are lost completely; the probability that this happens is denoted by  $\tilde{\alpha}$  (the determination of  $\tilde{\alpha}$  is discussed below). Finally, the household's *worker* sells the household's labour services ( $h_t$ ) at a real wage  $w_t^h$  and the household's physical capital ( $k_t^h$ ), at the rental rate  $r_t^k$ , to final good producers.

Because monetary injections are distributed to the households' financiers, they enter the economy through the financial markets and create an imbalance between the amount of funds present in financial markets and in the final good market. In principle, households could correct this imbalance by reducing the amount of liquidity they send to financial markets (i.e. increasing

$M_t^c$ ) but the presence of portfolio adjustments costs limits the extent to which they can do. As a consequence, some of the imbalance remains, leading to a reduction in the opportunity cost of funds in the financial market and thus downward pressure to nominal interest rates. This follows the recent limited participation literature, as in Dotsey and Ireland (1995), Christiano and Gust (1999) and Cooley and Quadrini (1999).

The maximization problem of a representative household is the following:

$$\max_{\{c_t^h, M_{t+1}, M_t^c, h_t, k_{t+1}^h\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left[ c_t^h - \chi \frac{(h_t + v_t)^\gamma}{\gamma} \right], \quad (1)$$

where  $\beta$  is the discount factor,  $c_t^h$  is the household's consumption,  $h_t$  its labour effort, and  $v_t \equiv \frac{\phi}{2} \left( \frac{M_t^c}{M_{t-1}^c} - \varphi \right)^2$  expresses the (time) cost of adjusting the household financial portfolio.<sup>5</sup> The expectation is taken over uncertainty about aggregate shocks to monetary policy and technology as well as over the idiosyncratic shock affecting each household (the outcome from the projects that the household indirectly finances through his association with a bank). The risk neutrality behaviour characterizing this utility function implies that households only value expected returns and do not seek to smooth out their consumption patterns.<sup>6</sup> The maximization is subject to both the cash-in-advance constraint:

$$c_t^h \leq \frac{M_t^c}{P_t}; \quad (2)$$

and the budget constraint:

$$\frac{M_{t+1}}{P_t} + q_t k_{t+1}^h = s_t \frac{r_t^d}{\tilde{\alpha}} \left( \frac{M_t - M_t^c + X_t}{P_t} \right) + \frac{M_t^c}{P_t} - c_t^h + w_t^h h_t + \left( r_t^k + q_t(1 - \delta) \right) k_t^h. \quad (3)$$

The cash-in-advance constraint (2) states that the real value of the shopper's cash position ( $\frac{M_t^c}{P_t}$ ) must be sufficient to cover planned expenditures of consumption goods ( $c_t^h$ ). The budget constraint (3) expresses the evolution of the household's assets, with the sources of income on the right-hand side of the equation, and the assets purchased on the left side. The first source of income is the return from the deposits ( $M_t - M_t^c + X_t$ ) invested by the household. We denote the expected return of these deposits by  $r_t^d$ . Hence, since  $\tilde{\alpha}$  is the probability of success of the entrepreneurial projects financed by the bank, the realized return is  $\frac{r_t^d}{\tilde{\alpha}}$  if the project is successful (an outcome indicated by  $s_t = 1$ ) and 0 otherwise ( $s_t = 0$ ). Three additional sources

<sup>5</sup>We follow Christiano and Gust (1999) in expressing the costs of adjusting financial portfolios in units of time.

<sup>6</sup>The assumption of risk neutrality is important for the financial contract between households, banks, and entrepreneurs discussed in Section 2.5.

of income are also present: any leftover currency from the shopper's activities ( $\frac{M_t^c}{P_t} - c_t^h$ ), the wage and capital rental income collected by the worker ( $w_t^h h_t + r_t^k k_t^h$ ), and the real value of the undepreciated stock of capital  $q_t(1-\delta)k_t^h$ , where  $q_t$  is the value of capital at the end of the period in terms of final goods. Total income is then transferred into financial assets (end-of-period real money balances  $M_{t+1}/P_t$ ) or holdings of physical capital ( $k_{t+1}^h$ ).

The first-order conditions of the problem with respect to  $c_t^h$ ,  $M_{t+1}$ ,  $M_t^c$ ,  $h_t$ , and  $k_{t+1}^h$  are the following:

$$1 = \lambda_{1t} + \lambda_{2t}; \quad (4)$$

$$\frac{\lambda_{2t}}{P_t} = \beta E_t \left[ \frac{\lambda_{2,t+1} r_{t+1}^d}{P_{t+1}} \right]; \quad (5)$$

$$\frac{\lambda_{2t} r_t^d}{P_t} + \chi(h_t + v_t)^{\gamma-1} v_1(\cdot_t) = \frac{\lambda_{1t} + \lambda_{2t}}{P_t} - \beta^h E_t [\chi(h_{t+1} + v_{t+1})^{\gamma-1} v_2(\cdot_{t+1})]; \quad (6)$$

$$\chi(h_t + v_t)^{\gamma-1} = \lambda_{2t} w_t^h; \quad (7)$$

$$\lambda_{2t} q_t = \beta^h E_t \left[ \lambda_{2,t+1} (r_{t+1}^k + q_{t+1}(1-\delta)) \right]. \quad (8)$$

In these expressions,  $\lambda_{1t}$  represents the Lagrange multiplier of the cash-in-advance constraint (2) and  $\lambda_{2t}$  a similar multiplier for the budget constraint (3).

Equation (4), equating the sum of the two Lagrange multipliers to 1, reflects the fact that the marginal utility of consumption is constant for the risk-neutral household. Equation (5) states that by choosing an extra unit of currency as a saving vehicle, the household is foregoing a utility value of  $\frac{\lambda_{2t}}{P_t}$ ; the household is compensated, in the next period, with the return from holding this extra unit of currency (the gross nominal interest rate  $r_{t+1}^d$ ) a return which, when properly deflated, discounted and expressed in utility terms, is valued at  $\beta E_t \left[ \frac{\lambda_{2,t+1} r_{t+1}^d}{P_{t+1}} \right]$ . Equation (6) states that by choosing to keep an extra unit of currency for use in the final good sector, the household foregoes the return associated with this extra unit if it had been sent to the financial sector ( $r_t^d$ ) and must also pay adjustment costs valued at  $\chi(h_t + v_t)^{\gamma-1} v_1(\cdot_t)$ . In return, the household receives the current period utility value of this extra liquidity ( $\lambda_{1t} + \lambda_{2t}$ ) and relaxes next period's expected portfolio adjustment costs by an amount valued at  $\beta E_t [\chi(h_{t+1} + v_{t+1})^{\gamma-1} v_1(\cdot_{t+1})]$ . Equations (7) and (8) are standard; notice, however, that because  $\lambda_2 < 1$ , inflation introduces a distortion in labour supply decisions.

### 2.3 Final good production

The final good sector features perfectly competitive producers that transform physical capital and labour inputs into the economy's final good. The production function they employ exhibits constant returns to scale and is affected by serially correlated technology shocks. The constant-returns-to-scale feature of the production function implies that we can concentrate on economy-wide relations, which coincide with the firm-level ones. Aggregate output  $Y_t$  is thus given by:

$$Y_t = z_t F(K_t, H_t^h), \quad (9)$$

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

$$z_t = \rho_z z_{t-1} + \epsilon_t^z, \quad \epsilon_t^z \sim (0, \sigma^z). \quad (10)$$

No financial frictions are present in this sector and the usual first-order conditions for profit maximization apply; aggregate profits of final good producers are zero. The competitive nature of this sector implies that the rental rate of capital and the real wage are equal to their respective marginal products:<sup>7</sup>

$$r_t^k = z_t F_1(K_t, H_t^h); \quad (11)$$

$$w_t^h = z_t F_2(K_t, H_t^h). \quad (12)$$

### 2.4 Capital good production

Each entrepreneur has access to a technology that uses units of the final good as input and produces capital goods. Specifically, an investment of  $i_t$  units of final goods contemporaneously yields a publicly observable return of  $Ri_t$  units of physical capital if the project succeeds, but zero units if it fails. Note that the investment size  $i_t$  will be specified by the lending contract between the entrepreneur and his financial backers.

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<sup>7</sup>To ensure that bankers and entrepreneurs can always pledge a non-zero amount of net worth in the financial contract negotiations, we also assume that the aggregate production function includes a small role for labour inputs from entrepreneurs and bankers, which entitles them to small wage payments every period (this follows Carlstrom and Fuerst (1997, 2001)). Since those wages do not affect the model's dynamics, we ignore them hereafter. Similarly, Chen (2001) assumes that entrepreneurs and bankers are entitled to modest levels of endowment each period.

Entrepreneurs can influence the riskiness of the projects they undertake. They may choose to pursue a project with low probability of success because it brings them private benefits. We follow the formulation of Holmstrom and Tirole (1997) and Chen (2001) and assume that there exists three types of projects, each carrying a different mix of public return and private benefits.<sup>8</sup> First, the *good* project involves a high probability of success (denoted  $\alpha^g$ ) and zero private benefits. Second, the low private benefit project, while associated with a lower probability of success  $\alpha^b$  ( $\alpha^b < \alpha^g$ ), generates private benefits proportional to the investment size and equal to  $b i_t$ . Finally, the high private benefit project, while also characterized by a low probability of success  $\alpha^b$ , provides higher private benefits to the entrepreneur, equal to  $B i_t$ , with  $B > b$ . The table below summarizes the probability of success and private benefits associated with the three projects. Given that the two latter ones have the same probability of success but different levels of private benefits, entrepreneurs would always choose the third one were monitoring not to be present.

| <b>Projects available to the entrepreneur</b> |            |                             |                               |
|---|------------|-----------------------------|-------------------------------|
| Project                                       | Good       | Low Private Benefit Project | High Private Benefit Project. |
| Private benefits                              | 0          | $b i_t$                     | $B i_t$                       |
| Probability of success                        | $\alpha^g$ | $\alpha^b$                  | $\alpha^b$                    |

Bankers have access to a monitoring technology that can detect whether entrepreneurs have undertaken the project with high private benefit, but this technology cannot distinguish between the other two projects.<sup>9</sup> Thus, if its bank monitors, the entrepreneur will not undertake the project with high private benefits. This is the socially preferable outcome because of the following assumption about returns:

$$q\alpha^b R + B - (1 + \mu) < 0 < q\alpha^g R - (1 + \mu), \quad (13)$$

where  $\mu$  is the monitoring cost of banks. Equation (13) states that even after accounting for the private benefit it provides, the overall economic return from the third project is negative. By contrast, the good project is economically viable.

<sup>8</sup>Including three projects enables us to consider imperfect bank monitoring that cannot completely eliminate the asymmetric information problem.

<sup>9</sup>Following Holmstrom and Tirole (1997) and Chen (2001), we interpret the monitoring activities of bankers as inspecting cash flows and balance sheets or verifying that firm managers conform with the covenants of a loan. This interpretation is different from the one given monitoring costs in the costly state verification (CSV) literature, where they are associated with bankruptcy-related activities.

Monitoring costs are assumed to be a fixed proportion  $\mu$  of project size  $i_t$ .<sup>10</sup> The monitoring activities of bankers are not, however, publicly observable. This creates an additional source of moral hazard that affects the relationship between bankers and their depositors (the households). To alleviate this problem, banks engage their own funds in the financing of projects. This creates an incentive to monitor entrepreneurs, in order to limit erosion of bank capital and reassures depositors, who can then provide more of their own funds towards the financing package.

The nature of the banker's activities is assumed to be such that all projects funded by a bank either succeed or all fail. This perfect correlation across project returns implies that banks cannot diversify their idiosyncratic risk of failure.<sup>11</sup> This strong assumption makes the solution of the model straightforward. It could be relaxed at the cost of added complexity: what is necessary for the mechanism described in the present paper to remain is that the correlation between project returns not be zero.<sup>12</sup>

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 funding with a mix of deposits it collects from the households ( $d_t$ ) as well as its own net worth (capital)  $a_t$ . Once the costs of monitoring the project ( $= \mu i_t$ ) are taken into account, the bank is able to lend an amount  $l_t^s = a_t + d_t - \mu i_t$ .

## 2.5 Financial contract

We concentrate on equilibria where the financial contract leads all entrepreneurs to undertake the good project;  $\alpha^g$  thus represents the probability of success of all projects and also the probability that households' deposits are repaid ( $\tilde{\alpha} = \alpha^g$ ). We also assume the presence of inter-period anonymity, which restricts the analysis to one-period contracts.<sup>13</sup>

The contract specifies what each of the three participants invests in the project and what

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<sup>10</sup>The proportionality in the monitoring costs and in private benefits facilitates the aggregation of individual contracts.

<sup>11</sup>The assumption of perfect correlation in the returns of bank assets is the opposite of the perfect diversification in Diamond (1984) and Williamson (1987), which allows bank to 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.

<sup>12</sup>The assumption that a given bank cannot diversify across his lines of business can be interpreted as a situation where a bank specializes along sectoral or geographical lines; in such a situation, the risk of failure will naturally be positively correlated across all projects.

<sup>13</sup>One-period contracts are also used by Carlstrom and Fuerst (1997) and Bernanke et al. (1999). General-equilibrium environments that pay explicit attention to dynamic contracting are found in Gertler (1992), Smith and Wang (2000), and Cooley et al. (2003).

they are promised in return, as a function of the project outcome. Recall that an investment of size  $i_t$  returns  $R i_t$  units of capital good if it is successful, and nothing if it fails. The (optimal) contract we focus on has the following structure: (i) the entrepreneur invests all available net worth, and the bank and the households put up the balance  $i_t - n_t$ , (ii) if the project succeeds, the unit return  $R$  is distributed among the entrepreneur ( $R_t^e > 0$ ), the banker ( $R_t^b > 0$ ) and the households ( $R_t^h > 0$ ), and (iii) all three agents receive nothing if the project fails.

The financial contract maximizes the entrepreneur's expected share of the return (which is equal to  $q_t \alpha^g R_t^e i_t$  if the good project is chosen) subject to a number of constraints. These constraints ensure that entrepreneurs and bankers have the incentive to behave as agreed and that the funds contributed by the banker and the household earn (market-determined) required rates of return. More precisely, the optimal contract is given by the solution to the following optimization program:

$$\max_{\{i_t, R_t^e, R_t^b, R_t^h, a_t, d_t\}} q_t \alpha^g R_t^e i_t, \quad (14)$$

subject to

$$R = R_t^e + R_t^h + R_t^b; \quad (15)$$

$$q_t \alpha^g R_t^b i_t - \mu i_t \geq q_t \alpha^b R_t^b i_t; \quad (16)$$

$$q_t \alpha^g R_t^e i_t \geq q_t \alpha^b R_t^e i_t + q_t b i_t; \quad (17)$$

$$q_t \alpha^g R_t^b i_t \geq r_t^a a_t; \quad (18)$$

$$q_t \alpha^g R_t^h i_t \geq r_t^d d_t; \quad (19)$$

$$a_t + d_t - \mu i_t \geq i_t - n_t. \quad (20)$$

Equation (15) states that the shares promised to the three different agents must add up to the total return. Equation (16) is the incentive compatibility constraint for bankers, which must be satisfied in order for monitoring to occur. It states that the expected return to the banker if monitoring, net of the monitoring costs, must be at least as high as the expected return if not monitoring, a situation in which entrepreneurs would choose the project with high private benefits and the low probability of success. Equation (17) is the incentive compatibility of entrepreneurs; given that bankers monitor, entrepreneurs cannot choose the high private benefit project, but still must be induced to choose the good project over the low private benefit

one. This is achieved by promising them an expected return that is at least as high as the one they would get, inclusive of private benefits, if they were to choose the low private benefit project. Equations (18) and (19) are the participation constraints of bankers and households, respectively. They state that these agents, when engaging bank capital  $a_t$  and deposits  $d_t$ , are promised shares of the project's return that cover the (market-determined) required rates of return on bank capital and household deposits (denoted  $r_t^a$  and  $r_t^d$ , respectively). Finally, equation (20) indicates that the loanable funds available to a banker (its own capital and the deposits it attracted), net of the monitoring costs, must be sufficient to cover the external funding requirements of the entrepreneur.<sup>14</sup>

In equilibrium, the constraints (16), (17), and (19) hold with equality, so that we have:

$$R_t^e = \frac{b}{\Delta\alpha}; \quad (21)$$

$$R_t^b = \frac{\mu}{q_t\Delta\alpha}; \quad (22)$$

$$R_t^h = R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t\Delta\alpha}; \quad (23)$$

where  $\Delta\alpha = \alpha^g - \alpha^b > 0$  and  $R_t^j > 0$  for  $j = e, b, h$ .

Note from (21) and (22) that the shares allocated to the entrepreneur and the banker are determined by the severity of the moral hazard problem that characterizes their actions. In turn, (23) 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 extent of these moral hazard problems. Were the private benefit  $b$  or the monitoring cost  $\mu$  to increase, the project share allocated to the entrepreneurs (or the banker) would have to increase; conversely, the maximal payment to households would decrease.

Introducing (23) in the participation constraint of households (19) holding with equality leads to the following:

$$r_t^d d_t = q_t \alpha^g \left( R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right) i_t, \quad (24)$$

whereas eliminating  $d_t$  from (24) using the resource constraint (20) and dividing by  $i_t$  leads:

$$r_t^d \left[ (1 + \mu) - \frac{a_t}{i_t} - \frac{n_t}{i_t} \right] = q_t \alpha^g \left( R - \frac{b}{\Delta\alpha} - \frac{\mu}{q_t \Delta\alpha} \right). \quad (25)$$

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<sup>14</sup>In what follows, we consider only contracts in which (20) holds with equality because these contracts dominate those in which the inequality is not binding when funds are invested in the good project.

This illustrates the mechanism by which monetary policy shocks affect the economy's leverage. All things equal, a monetary tightening (an increase in the required rate on deposits  $r_t^d$ ) does not affect the per-unit share of project return that can be promised to households (the right-hand side of 25). 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 a increase in the relative contributions of bank capital ( $a_t/i_t$ ) and entrepreneurial net worth ( $n_t/i_t$ ). Since bank capital and entrepreneurial net worth are largely predetermined, the project size  $i_t$  must decrease.

Solving for  $i_t$  in (25) yields:

$$i_t = \frac{n_t + a_t}{G_t}, \quad (26)$$

where  $G_t$  depends only on parameters and economy-wide variables:

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

In equilibrium,  $i_t$  is positive, so  $G_t$  must be positive (since  $a_t$  and  $n_t$  are both  $> 0$ ).<sup>15</sup> Expression (26) illustrates that the project size a given entrepreneur can undertake depends on its net worth as well as the capital his banker is pledging towards the project. Given an investment size  $i_t$ , the expected output of new capital is  $i^s(n_t, a_t; G_t) = \alpha^g R i_t$ . Once aggregated (see section 2.7 below) this can be interpreted as the supply curve for investment good. 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, (26) makes clear that increases in  $a_t$  or  $n_t$  shifts this supply curve to the right, whereas the the intuition discussed above with respect to equation (25) shows that increases in  $r_t^d$  shifts the curve to the left.<sup>16</sup>

Finally, we define the bank capital-asset ratio for this individual contract as follows:

$$ca_t = \frac{a_t}{(1 + \mu)i_t - n_t}. \quad (28)$$

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<sup>15</sup>This implies that rates of return and prices should be such that:

$$q_t \alpha^g (b + \mu/q_t) / \Delta \alpha > q_t \alpha^g R - r_t^d (1 + \mu),$$

which states that the sum of expected shares paid to the entrepreneur and banker is higher than the expected unit surplus of the good project.

<sup>16</sup>The demand for capital good is implicitly defined by (8), the first-order condition of the household problem with respect to  $k_{t+1}^h$ .

## 2.6 Entrepreneurs and Bankers

Entrepreneurs manage the investment projects of the economy. They have linear preferences summarized by the following expected lifetime utility:

$$E_0 \sum_{t=0}^{\infty} (\beta\tau^e)^t c_t^e, \quad (29)$$

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

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, so that  $\tau^e$  represents the probability of survival of an individual entrepreneur. Newborn entrepreneurs replace those that exit, so that the economy's population of entrepreneurs remains constant and equal to  $\eta^e$ . The assumption that entrepreneurs have finite lives ensures that they do not accumulate enough wealth to overcome the financial constraints.<sup>17</sup>

During the first part of the period, entrepreneurs raise internal funds by renting physical capital they carried over from previous periods to final goods producers. 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:<sup>18</sup>

$$n_t = r_t^k k_t^e + q_t(1 - \delta)k_t^e, \quad (30)$$

where  $r_t^k$  is the rental rate of capital in the final good sector,  $k_t^e$  is the beginning-of-period stock of physical capital held by the entrepreneur, and  $q_t$  is the end-of-period price of the capital good.

Bankers are agents endowed with a technology that allows them to monitor entrepreneurs. They arrange the financing of investment projects and act as delegated monitors for their depositors (the households). Like entrepreneurs, they are risk-neutral and face a constant probability of survival equal to  $\tau^b$ .<sup>19</sup> Their lifetime utility is thus:

$$E_0 \sum_{t=0}^{\infty} (\beta\tau^b)^t c_t^b, \quad (31)$$

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<sup>17</sup>Alternatively, Carlstrom and Fuerst (1997) assume that entrepreneurs are infinitely-lived but discount the future more heavily than households do.

<sup>18</sup>Since we assume that entrepreneurs also receive a very small wage, entering entrepreneurs have a small but non-zero stock of net worth.

<sup>19</sup>As 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  $\eta^b$ .

where  $c_t^b$  denotes bank consumption.

Bankers also raise internal funds to alleviate the effects of the financing constraints they are subject to. They rent their holdings of physical capital to final goods producers, so that bank capital ( $a_t$ ) is the following sum of rental income and undepreciated capital:

$$a_t = r_t^k k_t^b + q_t(1 - \delta)k_t^b, \quad (32)$$

where  $k_t^b$  is the beginning-of-period stock of physical capital held by an individual banker.

In the second part of the period, each entrepreneur-banker pair undertakes an investment project in which the entrepreneur invests his net worth  $n_t$  and the banker his capital  $a_t$ . The overall size of the project is  $i_t$ ; recall from (26) that it is related to net worth and bank capital by  $i_t = (n_t + a_t)/G_t$ .<sup>20</sup> As described above, an entrepreneur associated with a successful project receives a payment of  $R_t^e i_t$  whereas the corresponding banker receives  $R_t^b i_t$ ; unsuccessful projects have no return.

If they are exiting the economy, entrepreneurs and bankers associated with a successful project sell their share of the return to buy consumption goods. If they are continuing through the next period, they save their entire share; since they are risk-neutral and the return to internal funds is high, they prefer to postpone consumption. This optimizing behaviour is summarized by the following set of consumption and saving decisions:

$$c_t^J = \begin{cases} q_t R_t^J i_t & , \text{ if exiting and successful } (J = e, b) \\ 0 & , \text{ otherwise.} \end{cases} \quad (33)$$

$$k_{t+1}^J = \begin{cases} R_t^J i_t & , \text{ if surviving and successful } (J = e, b) \\ 0 & , \text{ otherwise.} \end{cases} \quad (34)$$

## 2.7 Aggregation

We denote aggregate variables by uppercase letters, in contrast to the lowercase individual variables. The linearity features of the model imply that aggregate investment ( $I_t$ ) is simply the economy-wide sum of individual investment projects as described in (26), so that we have:

$$I_t = \frac{N_t + A_t}{G_t}, \quad (35)$$

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<sup>20</sup>Recall also that the rest of the financing comes from household deposits  $d_t$ ; see (20).

where  $N_t$  and  $A_t$  denote aggregate entrepreneurial net worth and aggregate bank capital, respectively, and  $G_t$  was defined in equation (27). Notice that a fall in either  $A_t$  or  $N_t$  leads to a decrease in current investment, for given values of  $G_t$ . Further, note that the distribution of net worth and bank capital across agents in the economy has no effects on aggregate investment: keeping track of these distributions is thus not necessary.<sup>21</sup> Moreover, the bank capital-asset ratio defined in (28) can be aggregated to yield the following economy-wide measure:

$$CA_t = \frac{A_t}{(1 + \mu)I_t - N_t} = \frac{\frac{A_t}{N_t}}{(1 + \mu)\frac{I_t}{N_t} - 1}. \quad (36)$$

Finally, the economy-wide equivalent to (18) defines the equilibrium return on bank capital (equity) as follows:

$$r_t^a = \frac{\alpha^g \mu (1 + N_t/A_t)}{G_t \Delta \alpha}. \quad (37)$$

The aggregate levels of entrepreneurial net worth, bank capital, and holdings of physical capital ( $K_{t+1}^e$  and  $K_{t+1}^b$ ) are found by summing up (30), (32), as well as (34) across all individual entrepreneurs and bankers:

$$N_t = \left( r_t^k + q_t(1 - \delta) \right) K_t^e; \quad (38)$$

$$A_t = \left( r_t^k + q_t(1 - \delta) \right) K_t^b; \quad (39)$$

$$K_{t+1}^e = \tau^e \alpha^g R_t^e I_t; \quad (40)$$

$$K_{t+1}^b = \tau^b \alpha^g R_t^b I_t. \quad (41)$$

Combining (35)-(41) yields the following law of motion for  $N_{t+1}$  and  $A_{t+1}$ :

$$N_{t+1} = \left( r_{t+1}^k + q_{t+1}(1 - \delta) \right) \tau^e \alpha^g R_t^e \left( \frac{A_t + N_t}{G_t} \right); \quad (42)$$

$$A_{t+1} = \left( r_{t+1}^k + q_{t+1}(1 - \delta) \right) \tau^b \alpha^g R_t^b \left( \frac{A_t + N_t}{G_t} \right). \quad (43)$$

Equations (42) and (43) illustrate the interrelated evolution of bank capital and entrepreneurial net worth. Aggregate bank capital  $A_t$ , through its effect on aggregate investment (and hence on the retained earnings of the entrepreneurial sector), affects the future net worth of entrepreneurs as well as bank capital itself. Conversely, aggregate entrepreneurial net worth  $N_t$  has an impact on the future capital of the banking sector.

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<sup>21</sup>This results from the linear specification of the production function for capital goods, the private benefits, and the monitoring costs.

Finally, the aggregation of (33) across all entrepreneurs and bankers yield the following expressions for aggregate consumption by these agents:

$$C_t^e = (1 - \tau^e)q_t\alpha^g R_t^e I_t(N_t, A_t); \quad (44)$$

$$C_t^b = (1 - \tau^b)q_t\alpha^g R_t^b I_t(N_t, A_t). \quad (45)$$

## 2.8 Monetary policy

Monetary authorities control the total supply of money in the economy. Denote beginning-of-period supply as  $\overline{M}_t$  and the injection of new money during the period as  $X_t$ , so that  $\overline{M}_{t+1} = \overline{M}_t + X_t$ . Following Christiano and Gust (1999), monetary policy is interpreted as choosing  $X_t$  so that a nominal deposit rate  $r_t^d$  consistent with the monetary authorities' target is achieved.

Consistent with Taylor (1993), we specify that the interest rate targeting rule followed by monetary authorities reacts to deviations of inflation and aggregate output from their steady-state values:

$$r_t^d/r^d = (Y_t/Y)^{\rho_y}(\pi_t/\pi)^{\rho_\pi} e^{\epsilon_t^{mp}}, \quad \epsilon_t^{mp} \sim (0, \sigma^{mp}); \quad (46)$$

where  $r^d$ ,  $Y$ , and  $\pi$  are the steady-state values of  $r_t^d$ ,  $Y_t$ , and  $\pi_t$ , respectively ( $\pi_t$  is the gross rate of increase in the price level), and  $\epsilon_t^{mp}$  is an *i.i.d* monetary policy shock, that is instances where monetary authorities depart from the systematic portion of their rule (46).<sup>22</sup>

## 2.9 The competitive equilibrium

The recursive, competitive equilibrium for the economy consists of i) decision rules for  $c_t^h$ ,  $M_{t+1}$ ,  $M_t^c$ ,  $h_t$ , and  $k_{t+1}^h$  that solve the maximization problem of the household as expressed in (1)-(3), ii) decision rules for  $H_t$  and  $K_t$  that are consistent with the first-order conditions in (11)-(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 (14)-(20), iv) the saving and consumption decision rules of entrepreneurs and bankers (33)-(34), and v) the following market clearing conditions:

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<sup>22</sup>Taking logs of the rule in (46) leads to a form more familiar in the literature:

$$\log(R_t^d/R^d) = \rho_y \log(Y_t/Y) + \rho_\pi \log(\pi_t/\pi) + \epsilon_t^{mp}.$$

1. In the labour market, aggregate demand by final good producers equals the sum of individual supply of households:

$$H_t = \eta^h h_t; \quad (47)$$

2. Total demand of physical capital by final good producers equals the sum of individual holdings of capital:

$$K_t = \eta^h k_t^h + \eta^e k_t^e + \eta^b k_t^b; \quad (48)$$

3. In the market for final goods, aggregate production equals aggregate consumption and aggregate investment, inclusive of monitoring costs:

$$Y_t = C_t^h + C_t^e + C_t^b + (1 + \mu)I_t; \quad (49)$$

where  $C^h$  denote aggregate consumption by households.

4. In the market for capital goods, aggregate net demand equals the production from successful investment projects:

$$K_{t+1} = (1 - \delta) K_t + \alpha^g R I_t; \quad (50)$$

5. The total demand of funds from bankers equal the sum of households' deposits and monetary injections from the central bank:

$$\frac{q_t \alpha^g [R - b/\Delta\alpha - \mu/q_t \Delta\alpha] I_t}{r_t^d} = \frac{\overline{M}_t - M_t^c + X_t}{P_t}; \quad (51)$$

### 3 Calibration

The model's parameters are calibrated in a manner that ensures certain features of the non-stochastic steady state approximately match their empirical counterparts. Further, whenever possible, we follow the calibration procedures of recent contributions to the agency problem literature (Carlstrom and Fuerst, 1997; Bernanke et al., 1999), in order to facilitate the comparison of our results with those featured in these models.

The discount factor  $\beta$  is set at 0.99, so that the average real rate of return on deposits is around 4 percent.<sup>23</sup> We set  $\gamma$ , the curvature parameter on labour effort in the utility function,

<sup>23</sup>Recall that bank deposits should be interpreted as relatively illiquid assets that provide a higher return than more liquid ones.

to a value of 2.0; this implies that the steady-state wage elasticity of labour supply is 1. The scaling parameter  $\chi$  is determined by the requirement that steady-state labour effort be 0.3.

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

$$Y_t = z_t K_t^{\theta_k} H_t^{\theta_h}, \quad (52)$$

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

$$z_t = \rho_z z_{t-1} + \epsilon_t^z, \quad \epsilon_t^z \sim (0, \sigma^z). \quad (53)$$

We set  $\theta_k$  to 0.36 and  $\theta_h$  to 0.64. The autocorrelation parameter  $\rho_z$  is 0.95 while  $\sigma^z$ , the standard deviation of the innovations to  $z_t$ , is fixed at 0.01.

Monetary policy is assumed to take the form of the original 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 standard deviation of the innovations to the rule  $\sigma^{mp}$  is also set to 0.01.

The parameters that remain to be calibrated ( $\alpha^g$ ,  $\alpha^b$ ,  $b$ ,  $R$ ,  $\mu$ ,  $\tau^e$ ,  $\tau^b$ ) are linked more specifically to the capital good production and the financial relationship linking entrepreneurs to banks and households. We set  $\alpha^g$  to 0.9903, so that the (quarterly) failure rate of entrepreneurs is 0.97 percent, 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 capital-asset ratio ( $CA$ ) of around 15 percent (close to the average risk-weighted ratio of US banks in 2002, according to BIS data); 2) a leverage ratio (the size of entrepreneurial projects relative to their accumulated net worth,  $I/N$ ) of 2.0; 3) a ratio of bank operating costs to bank assets ( $BOC$ ) of 5 percent, which matches the developed economies' estimate in Erosa (2001); 5) a net return on bank capital (bank equity,  $ROE$ ) equal to 15 percent on an annualized basis, a figure close to those reported in Berger (2003) for the late 1990s; 6) ratios of aggregate investment to output and capital to output of 0.2 and 4, respectively. 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,  $\mu$ , is equal to 0.025.

We conduct some experiments where  $\mu$  is either increased (to  $\mu = 0.05$ ) or decreased ( $\mu =$

0.01). The former situation corresponds to a case where the information friction between banks and depositors is more severe and the latter to a situation where it is less severe. Note from Table 1 that when  $\mu = 0.05$ , depositors require banks to engage more of their own net wealth in the financing of a give-size project, so that the steady-state values of the capital-asset ratio is increased to 31%. Conversely, with  $\mu = 0.01$ , the capital-asset ratio decreases to 6%. Section 6.1 examines the implications of these changes in parameter values for the effects of monetary policy tightenings. 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 (1998).

**Table 1: Parameter Calibration**

| Household Preferences                  |          |            |            |                   |                   |          |
|--|----------|------------|------------|-------------------|-------------------|----------|
|  | $\chi$   | $\gamma$   | $\phi$     | $\beta$           |                   |          |
|  | 2.75     | 1.5        | 5.0        | 0.99              |                   |          |
| Final Good Production                  |          |            |            |                   |                   |          |
|  | $\delta$ | $\theta_k$ | $\theta_h$ | $\theta_e$        | $\theta_b$        | $\rho_z$ |
|  | 0.02     | 0.36       | 0.6399     | $5 \cdot 10^{-5}$ | $5 \cdot 10^{-5}$ | 0.95     |
| Capital Good Production                |          |            |            |                   |                   |          |
|  | $\mu$    | $\alpha^g$ | $\alpha^b$ | $R$               | $b$               |          |
| Baseline                               | 0.025    | 0.97       | 0.67       | 0.5               | 0.09              |          |
| More Severe Friction                   | 0.05     | 0.97       | 0.67       | 0.5               | 0.06              |          |
| Less Severe Friction                   | 0.001    | 0.97       | 0.67       | 0.5               | 0.06              |          |
| Resulting Steady-State Characteristics |          |            |            |                   |                   |          |
|  | $CA$     | $I/N$      | $BOC$      | $ROE$             |                   |          |
| Baseline                               | 15%      | 2.0        | 5%         | 15%               |                   |          |
| More Severe Friction                   | 31%      | 1.91       | 11%        | 15%               |                   |          |
| Less Severe Friction                   | 6%       | 2.06       | 2%         | 15%               |                   |          |

## 4 The Transmission of Shocks

In order to illustrate the mechanism by which shocks affect the economy, Figure 2 presents the model's response to a contractionary disturbance to the monetary policy rule in (46), i.e.  $\epsilon_t^{mp} = -0.01$ . This shock increases the opportunity cost of the deposits that form part of the external

financing banks arrange for entrepreneurs. This increase in the cost of deposits leads banks to tighten lending, which in turn causes a fall in the scale of the investment projects entrepreneurs are able to undertake. This reduction in project scale means that both entrepreneurs and banks cannot leverage their net worth as much as they could before: this is reflected in the fall of the leverage ratio  $I_t/N_t$  and in the increase in the capital-asset ratio of banks  $CA_t$ . Note that this counter-cyclical movement in the capital-asset ratio is market-determined.

Intuition about this result can be developed using equation (25), which stated:

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

Recall that the per-unit share of project return that can be paid to households deposits (the right-hand side of the equation) is limited by the double moral hazard problem. This limitation means that the increase in  $r_t^d$  must be met with a reduction in the reliance on deposits (a decrease in  $d_t$ ) for the financing of a given-size project. In turn banks and entrepreneurs are required to invest more of their own net worth in the financing of that given size project: the ratios  $a_t/i_t$  and  $n_t/i_t$  must increase, so that bank capital-asset ratios increases while entrepreneurial leverage falls. As the levels of entrepreneurial net worth  $n_t$  and bank capital  $a_t$  are for a large part predetermined (they consist of accumulated, retained earnings from past periods : recall equations 38 and 39), most of the adjustment is borne by a decrease in the size of investment projects bankers can finance, i.e. by decreases in project size  $i_t$ . At the level of the economy, these reductions in project size result in a decrease in aggregate investment  $I_t$ .

Another way to interpret this result is that increases in the deposit rate  $r_t^d$  worsens the moral hazard problem affecting the relationship between banks and households. Depositors now need to better remunerated for their deposits and it becomes harder to satisfy their participation constraint while keeping the contract incentive-compatible. To alleviate this situation, banks are lead to pledge more of their own capital in the financial contract.

The increase in  $r_t^d$  thus acts like a shift to the left in the supply of investment goods and leads to an increase in the price of new capital. Earnings of banks and entrepreneurs also fall, due to reduced scale of investment projects. Because entrepreneurial net worth and bank capital consists of past retained earnings, which in turn depend on the scale of investment, the initial fall in investment leads to extended declines in the stock of entrepreneurial net worth and bank

capital. Because the interest rate returns to its steady-state level immediately after the impact period, it is those declines that propagate the shock over time, restricting the scale of investment projects and depressing capital accumulation and output for several periods.

Notice that output increases slightly on impact, before experiencing significant and prolonged decreases in subsequent periods. This results from the fact that as written, the cash-in-advance constraint (2) implies that inflation distorts the labour supply decisions of households. In the following section, the form of the cash-in-advance constraint is modified and the small increase of output at the onset of the shock disappears.

Expression (25) shows that increases in  $q_t$  have similar effects on the determination of project size that increases in  $r_t^d$ . This suggests that the effects of adverse technology shocks resemble those of contractionary monetary policy shocks. Figure 3 verifies this intuition, by reporting the effect of a decrease of 1% to technology  $\epsilon_t^z$ ; recall equation (10). The reduction in the productive capacities of final good producers implies that the rental rate on physical capital will be low for several periods (recall that the technology shocks are persistent). This lowers the demand for physical capital and, were the supply curve of investment goods not to shift, would result in a decrease in  $q_t$ , the price of newly created capital goods, and in investment.

However, the adverse technology shock also produces upward pressures on inflation; considering the rule (46) followed by monetary authorities, this implies that nominal interest rates must rise. This rise acts as a negative shift in the supply of investment goods, following the intuition sketched out above. In the experiment illustrated in Figure 3, this supply channel is significant and the price of capital goods  $q_t$  actually falls, while investment drops very significantly.

Similarly to the monetary policy shocks, these investment decreases lead to lower entrepreneurial net worth and bank capital in subsequent periods, which continue to propagate the shock through their negative impact on the supply of investment goods.

## 5 The Extended Model

Up to this point the quantitative model in which we embed the financial contract lacked the features necessary to make our analysis comparable to those contained in standard monetary versions of the real-business cycle model, e.g. Christiano and Gust (1999) and Cooley and

Quadrini (1999). We now extend the model in order to make this comparison possible.

Specifically, we assume that households are risk-averse, that the cash-in-advance constraint faced by households is more involved than the one we have described so far, and that financing from banks is required not only for entrepreneurs but also for final good producers.

The introduction of risk-aversion in the utility of households implies that their intertemporal maximization problem is now the following:

$$\max_{\{c_t^h, M_{t+1}, M_t^c, h_t, h_{t+1}^h\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left[ \log(c_t^h) - \chi \log(1 - h_t - v_t) \right], \quad (54)$$

with  $h_t$  hours worked and  $v_t$  the time costs of adjusting financial portfolios. The presence of risk-aversion means that households now seek to smooth their consumption path and thus that they are now less ready to experience big swings in consumption to take advantage of temporary low price of investment goods. Further, the smoothing motive has important implications for the behaviour of labour supply, and therefore for the determination of the economy's total output.

The financial contract in equations (14) to (20), however, was derived under the assumption that all three parties to the contract were risk neutral. To resolve this difficulty, we introduce an insurance scheme that insures households against all idiosyncratic risk related to the financial contract.<sup>24</sup> The return on deposits is now supplemented by the (net) insurance payments, so that the (now risk-free) rate of return on financial assets is  $r_t^d$ . This effectively renders the households risk-neutral with respect to the financial contract because idiosyncratic risk has been diversified away and the production of capital good does not feature any aggregate risk.<sup>25</sup> The insurance scheme allows us to treat the model as a representative agent one.

The second added feature is that the cash-in-advance constraint is comparable to those used by recent monetary models (Cooley and Quadrini, 1999). We assume that the current wage income of households is available for purchasing consumption in the current period. This feature eliminates the distortion to the labour supply decision of households that expected inflation causes in the basic model. Further, we also assume that the household's purchases of physical capital must be paid with cash. Inflation therefore now distorts the investment demand of households.

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<sup>24</sup>This follows Andolfatto (1996) and Cooley and Quadrini (1999).

<sup>25</sup>Derivations are available from the authors. See (Carlstrom and Fuerst, 1998, pg. 587) for further discussions. Alternatively, Carlstrom and Fuerst (1997) assume the existence of a mutual fund that pools all savings from households and invests these funds in banks, thus diversifying away idiosyncratic risk.

The combination of risk aversion (along with perfect insurance) and the inclusion of wage income and physical capital purchases in the cash-in-advance constraint leads us to rewrite equations (2) and (3) so that the new cash-in-advance constraint is as follows:

$$c_t^h + q_t \left( k_{t+1}^h - (1 - \delta)k_t^h \right) \leq \frac{M_t^c}{P_t} + w_t^h h_t; \quad (55)$$

while the budget constraint is now:

$$\frac{M_{t+1}}{P_t} = \frac{M_t^c}{P_t} + w_t^h h_t - c_t^h - q_t \left( k_{t+1}^h - (1 - \delta)k_t^h \right) + r_t^d \left( \frac{M_t - M_t^c + X_t}{P_t} \right) + r_t^k k_t^h. \quad (56)$$

Assuming that wage income enters the cash-in-advance constraint begs the question of how final good producers can pay the households' wage income in cash. To resolve this issue, we postulate that final good producers also borrow funds from banking institutions, in order to pay for their wage bill. There is no information asymmetry problem involved in these types of loans. As a result, bank capital is not necessary to conduct this type of lending because moral hazard and monitoring are not an issue.<sup>26</sup> We assume, without loss of generality, that there are two types of financial intermediaries. First, banks as described until now, which lend to entrepreneurs and use their monitoring technology to resolve the moral hazard affecting production in that sector. Second, banking agents that transfer funds from households to final good producers without encountering any information problem and who don't hold capital. Defining these two types of lending and financial intermediaries is reminiscent of the modelling framework of Bernanke and Gertler (1985). 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, its intermediaries make zero profits.

The market clearing condition for deposits now reflects the fact that the supply loanable funds, which arises from households' savings decision and monetary injections  $\left( \frac{\overline{M}_t - M_t^c + X_t}{P_t} \right)$  must be divided by the two different classes of lending; equation (51) thus becomes:

$$\frac{[R - b/\Delta\alpha - \mu/q_t\Delta\alpha] I_t}{r_t^d} + w_t^h H_t = \frac{\overline{M}_t - M_t^c + X_t}{P_t}, \quad (57)$$

where the added demand for deposits is the wage bill of final good producers ( $w_t^h H_t$ ).

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<sup>26</sup>These loans are similar to those that are featured in standard monetary models, see Christiano and Gust (1999) and Cooley and Quadrini (1999). They should be interpreted as corresponding to the 'working capital' of big firms.

Finally, the market-clearing wage rate now reflect the fact that wage costs are borrowed, making the nominal interest rate a distortion that affects labour demand. Consequently, the complete model adds another dimension along which monetary policy contractions affect the economy, by reducing the demand for labour stemming from the activities of final good producers. Equation (12) is now the following:

$$w_t^h = z_t F_2(K_t, H_t) / r_t^l, \quad (58)$$

where  $r_t^l$  is the rate at which final good producers are able to get funding. Perfect competition in the second type of lending ensure that  $r_t^l = r_t^d$  in equilibrium. The calibration of the complete model is the same as the one described in Section 3, because consumption smoothing only affects the dynamic responses of the economy and not the features of the non-stochastic steady state.

Figure 4 shows that responses of the extended model to the same contractionary monetary policy shock that was discussed in Section 4 above. First, notice that the responses, while qualitatively similar to those in the basic model (Figure 2) exhibit smoother paths. The limited intertemporal elasticity of substitution now leads the economy to converge back to initial steady-state values much faster following the shock. Further, even though the size of the monetary policy shock is the same in the two experiments, the actual increase in the nominal interest rate is now modest, relative to what it was in the basic model (see Figure 2). This reduces the size of the leftward shift of the investment supply curve, thus limiting the downward pressures on aggregate investment and the upwards pressures on  $q_t$ , the price of the capital good. Finally, note that compared to Figure 2, the responses of investment are now characterized by a hump-shape response.<sup>27</sup> The responses of the extended-model economy to a technology shock (not reported) also exhibit the same qualitative features as those that were displayed in Figure 3 for the basic model. As is the case for the monetary policy shocks, the interest rate response is much smaller, which reduces the extent to which the investment supply shifts and alleviates, at least initially, the upward pressure on  $q_t$ .<sup>28</sup>

<sup>27</sup>On that dimension, our model is thus able to replicate the hump shape in the response of investment that Carlstrom and Fuerst (2001) report. We are able to generate this hump shape in an environment with finite-lived agents, whereas they found that only their framework with infinitely-lived, impatient entrepreneurs generated a hump shape in investment.

<sup>28</sup>The responses of the extended-model economy to a technology shock are available from the authors on request.

## 6 Bank Capital, Capital-Asset Ratios, and Monetary Policy

### 6.1 The importance of bank capital

In order to better assess the influence that bank capital has on the transmission of monetary policy shocks, Figure 5 compares the responses of two economies following the same contractionary monetary policy shock. First, full lines repeat the responses displayed in Figure 4 for the baseline economy. The second set of responses (the dashed lines) reflect those of an economy where the financial friction between banks and their depositors is eliminated. In such a case, the actions of banks are perfectly observable so depositors know if banks monitor. As a result, banks are not required to engage their own new worth (their capital) in the financing of the projects; bank capital becomes unnecessary and is therefore not held in equilibrium.

The alternative economy features higher entrepreneurial leverage than the baseline economy does, i.e.,  $G$  takes on a value of 0.51 in the baseline model but only 0.48 in the alternative economy (recall from (26) and (27) that  $G$  is approximately the inverse of entrepreneurial leverage). This implies that for a given level of entrepreneurial net worth, the investment project size that an entrepreneur can undertake is significantly lower in the baseline economy; see equation (35).

Figure 5 shows that the effects of a given monetary policy shock are dampened in the case where bank capital is present, relative to the case with no financial frictions. Specifically, both the impact effect on aggregate investment ( $-0.39\%$ ) and the maximal impact ( $-0.58\%$ ) are reduced, from their levels of  $-0.58\%$  and  $-0.70\%$ , respectively. The responses of output are also reduced, but to a lesser extent. Thus, a given increase in the cost of deposits  $r_t^d$ , because of the lower leverage of the baseline economy, leads to less significant tightening in bank lending, and less decreases in the scale of projects and thus aggregate investment. Moreover, the half-life of the shock on investment is increased (from 9 to 10 periods) when the financial friction on banks is present: there is therefore some evidence that the persistence of shocks has increased from the addition of a second source of moral hazard.

These results can be interpreted as an extension to those in Carlstrom and Fuerst (1998, 2001), where the introduction of a single source of agency cost in an otherwise standard business cycle model dampens the effect of economic shocks but increases their persistence, relative to an environment where there are no agency costs. Our results show that introducing a *second* source

of moral hazard further dampens these responses while increasing their persistence further.

Figure 6 illustrates the same mechanism, but from a different angle. In that figure, the severity of the financial friction is first increased (the dashed lines) and then decreased (the pointed lines). The figure shows that the response of investment and output to monetary policy shocks is significantly affected by the severity of the friction: the more severe the friction, the lower the amplitude of the responses, and to some extent, the more persistence they are.<sup>29</sup>

To understand these results, consider once more equation (25). When the information friction is eliminated,  $\mu$  does not appear on the right-hand side of the equation. The per-unit share of an investment project that can be allocated to households is thus higher. For a given (steady-state) value of the nominal deposit rate, financing projects is now easier and relies relatively more on household deposits, resulting in a high (steady-state) value of  $d_t/i_t$ . This relatively big share of household deposits in the financing of projects makes it difficult to replace such deposits when their opportunity cost increases following a monetary tightening. Said otherwise, an increase in deposit rates worsens the moral hazard problem affecting the relationship between households and banks *less* in an environment where the agency problem is already severe; in such an environment, banks already hold relatively high stocks of capital and pledging more of it per unit of investment project (to replace household deposits) is less difficult.

A given increase in  $r_t^d$  thus leads to more substantial decreases in aggregate investment in the economy where banks face little financial frictions. This deeper decline in investment leads to deeper declines in future entrepreneurial net worth and bank capital (through the retained earnings effect), which continue to propagate the shock in subsequent periods, after the initial effects of the rate increase have dissipated.

## 6.2 Cyclical Properties of the Bank Capital-Asset Ratio

Although there are no regulatory capital requirements in our model, we have showed that the market-generated bank capital-asset ratios will vary with the business cycle, reacting counter-cyclically to monetary and technology shocks. Since one objective of the updated Basle Accord on capital adequacy requirements is to facilitate, through harmonized measurements and increased disclosure, the exercise of market discipline over banks, it is natural to ask whether our

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<sup>29</sup>Similar effects are present when the economy is subjected to technology shocks.

model, in which all movements in the capital-asset ratio are market-generated, can replicate some of the cyclical properties of bank capital-asset ratios.

Such a comparison between the available data for the US and our model implications is illustrated in Table 2. First, we document the facts. Bank capital-asset ratios are measured as the sum of *tier1* and *tier2* capital over risk-weighted assets.<sup>30</sup> Panel A of Table 2 shows that measured bank capital-asset ratios in the United States are roughly half as volatile as output, while investment and bank lending are approximately four times as volatile. The table also shows that capital-asset ratios are countercyclical in the data, particularly with respect to investment and bank lending. Since bank capital moves fairly smoothly in the date, the countercyclical nature of capital-asset ratios we document is intimately related to many discussions about the procyclical nature of bank lending. The key message we take away from these data is that capital-asset ratios, although not very volatile, are significantly and negatively related to measures of bank lending and general economic activity.<sup>31</sup>

Turning now to Panel B of the table, we find that our model, when subjected to monetary policy and technology shocks, replicates fairly well the countercyclical movements of the capital-asset ratio relative to investment, bank lending and GDP. These similarities between the dynamic features implied by the model and those observed in the data suggests that market discipline may have played an important role in shaping the evolution of bank capital and the capital-asset ratio of banks over the recent monetary history. This also suggests that markets do have the capacity to provide beneficial discipline over the behaviour of banks and that the promotion of this discipline should be continued, most specifically by increasing the importance of ‘Pillar 3’ in the new Basle Accord.<sup>32</sup> Further, warnings about the proposals to make the new regulatory capital requirements themselves countercyclical should appeal to well-defined reasons for which

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<sup>30</sup>According to the Basle regulations, *tier1* capital is comprised of equity capital and published reserves from post-tax retained earnings. On the other hand, *tier 2* capital is composed of undisclosed reserves, asset revaluation reserves, general provisions, hybrid debt/equity capital instruments, and subordinated debt. The weights on different classes of assets range from zero on cash and other liquid instruments, to 50% for loans fully secured by mortgage on residential properties, to 100% on claims to the private sector. These data are averages for all US banks and are from the BIS.

<sup>31</sup>Note that an alternative measure of capital-asset ratios, which might match better with the corresponding measure in the model, is the ratio of capital over loans. The countercyclicity identified in Table 2 is also present when this alternative measure is used.

<sup>32</sup>The proposed new Basle accords on capital requirements contain three ‘pillars’: minimum regulatory requirements, supervision, and market discipline. See Rochet (2003) 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.

to overcome what may be optimal responses to economic shocks.

**Table 2. Cyclical Properties of the Capital-Asset Ratio: Model and Data**

| Variable                      | $\frac{\sigma(X)}{\sigma(GDP)}$ | <i>Cross-Correlation of the Capital-Asset Ratio with:</i> |           |           |       |           |           |           |
|-------------------------------|---------------------------------|---|-----------|-----------|-------|-----------|-----------|-----------|
|                               |                                 | $X_{t-4}$   | $X_{t-2}$ | $X_{t-1}$ | $X_t$ | $X_{t+1}$ | $X_{t+2}$ | $X_{t+4}$ |
| <i>Panel A: US Economy</i>    |                                 |   |           |           |       |           |           |           |
| Capital-Asset Ratio           | 0.38                            | 0.47  | 0.79      | 0.91      | 1     | 0.91      | 0.79      | 0.47      |
| Fixed Non Res. Investment     | 4.41                            | -0.44   | -0.48     | -0.44     | -0.38 | -0.28     | -0.20     | -0.02     |
| GDP                           | 1                               | -0.47   | -0.40     | -0.27     | -0.16 | -0.00     | 0.08      | 0.12      |
| Bank Lending (C & I)          | 4.67                            | -0.42   | -0.67     | -0.75     | -0.80 | -0.76     | -0.69     | -0.40     |
| <i>Panel B: Model Economy</i> |                                 |   |           |           |       |           |           |           |
| Capital-Asset Ratio           | 0.53                            | 0.85  | 0.94      | 0.98      | 1     | 0.98      | 0.94      | 0.85      |
| Fixed Non Res. Investment     | 2.60                            | -0.07   | -0.21     | -0.32     | -0.44 | -0.52     | -0.57     | -0.60     |
| GDP                           | 1                               | -0.12   | -0.25     | -0.35     | -0.45 | -0.47     | -0.48     | -0.47     |
| Bank Lending                  | 2.70                            | -0.10   | -0.25     | -0.37     | -0.51 | -0.56     | -0.59     | -0.59     |

*Note* For the US economy, 1990:1-2003:1. Capital-Asset Ratio: *tier1 + tier2* capital over risk weighted assets (source BIS); Fixed Non Res. 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.

## 7 Conclusion

This paper presents a monetary, quantitative, dynamic model of the interrelations between bank capital and entrepreneurial net worth, on the one hand, and monetary policy and economic activity, on the other. The model features two distinct sources of moral hazard. The first, arising because entrepreneurs can privately influence the probability of success of the projects they engage in even in the presence of bank monitoring, leads banks to require that entrepreneurs invest their own net worth in the projects they undertake. The second, which is based on the fact that the monitoring activities of banks are themselves not publicly observable, induces households to require that banks invest their own capital in entrepreneurial projects before depositing funds at banks. Entrepreneurial net worth and bank capital are thus key determinants of the propagation over time of shocks affecting the economy, even after the initial, direct impact of the original disturbances have faded away.

Quantitative simulations conducted with the model show that the presence of bank capital can have a significant impact on the amplitude and, to a lesser extent, on the persistence of the effects of monetary policy shocks. Specifically, monetary policy contractions have dampened but more persistent effects in our environment, where the financial friction between banks and their depositors constrain the leverage of entrepreneurs, than in an economy where the friction is eliminated and bank capital is not necessary. Further, the market-determined capital-asset ratio of banks reacts counter-cyclically to shocks, tightening credit when adverse shocks affect the economy; we document that this countercyclical behaviour is also present in aggregate US data.

Future work will analyze a version of the model that would position the double incidence of moral hazard in the sector producing the final good, rather than the present situation where it is the creation of new capital goods that is affected by the agency problems. Contrasting these two frameworks would allow us to link our results better to those in Carlstrom and Fuerst (1998, 2001) and the comparisons between the ‘output’ and ‘investment’ model they discuss. Further, it would be useful to analyze environments where the distribution of entrepreneurial net worth and bank capital matters for the aggregate implications of the model.

Second, a thorough examination of the role of bank capital in the transmission of economic shocks should 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.<sup>33</sup> An environment where such heterogeneity can arise from the dynamic effects of idiosyncratic shocks could yield further insights on the importance of bank capital for monetary policy.

Finally, the introduction of externalities, possibly because the liabilities of banks circulate and are used as means of payments, holds much promise. Such a framework could lead to a potential role for government intervention in the banking sector, perhaps as the result of large bank failures that impact on viability of the exchange mechanism.

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<sup>33</sup>This heterogeneity is documented, for the United States, in Ennis (2001b).

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# Timing of Events

Figure 1: Timing of Events

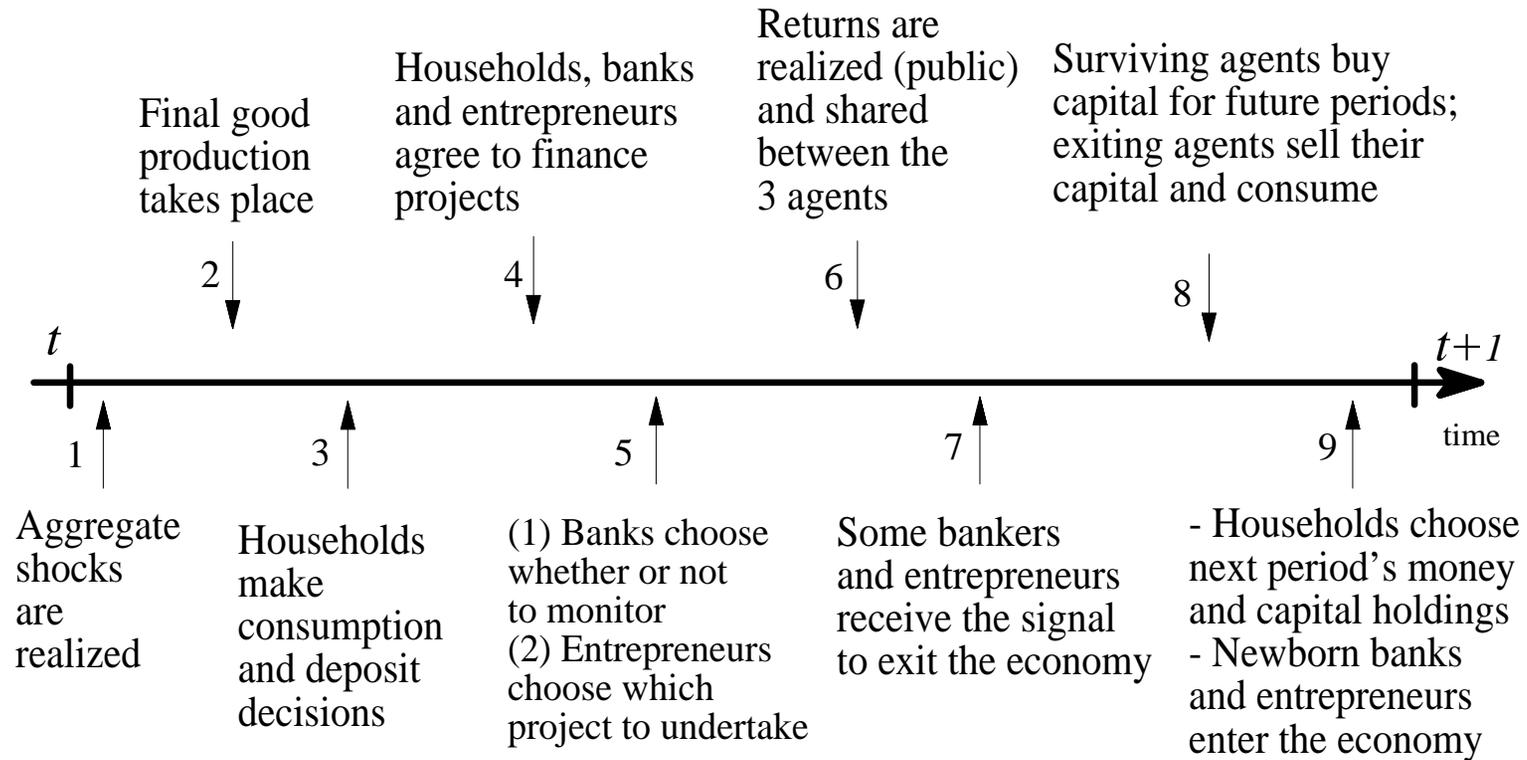


Figure 2. Contractionary Monetary Policy Shock: Basic Model

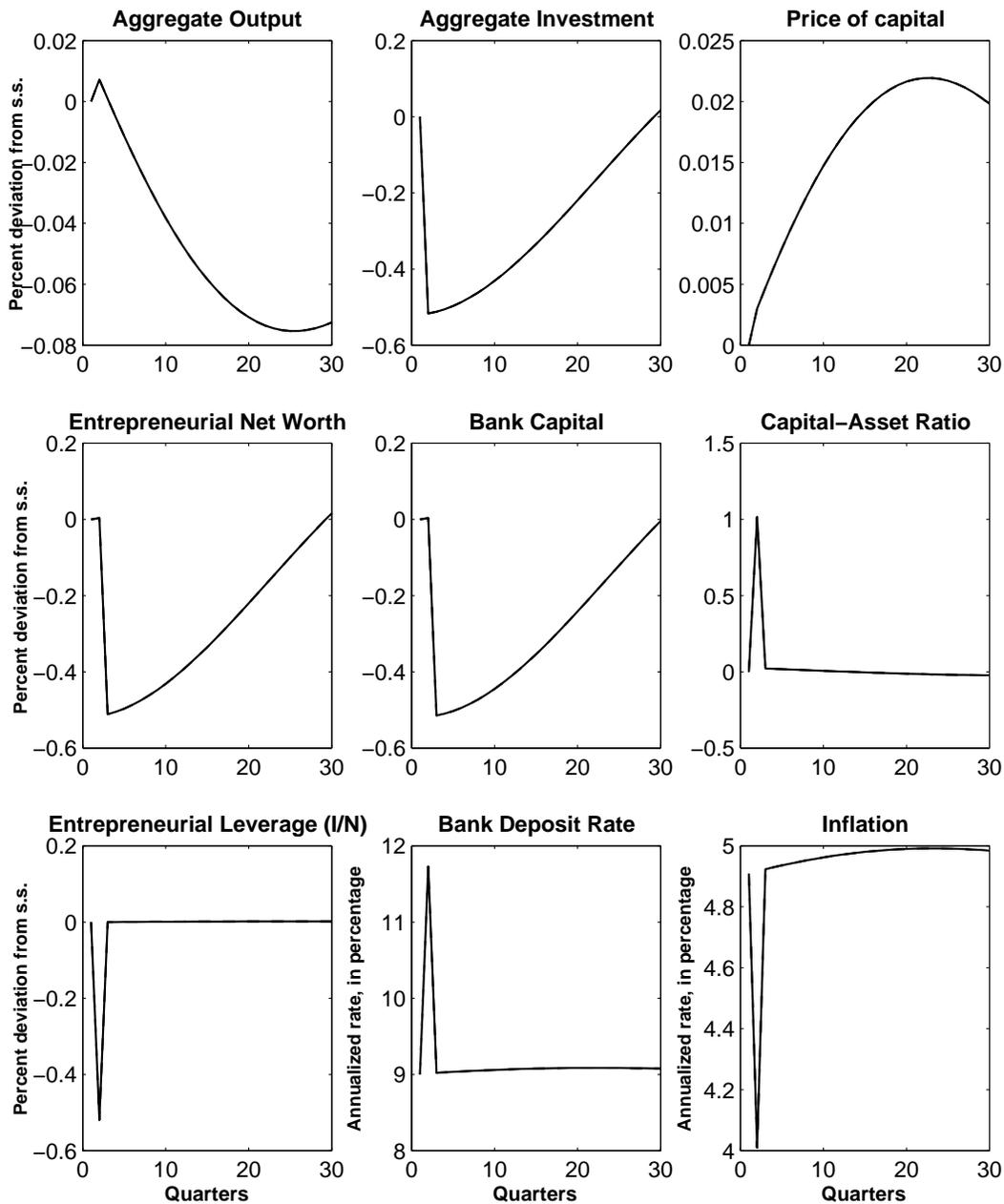


Figure 3. Adverse Technology Shock: Basic Model

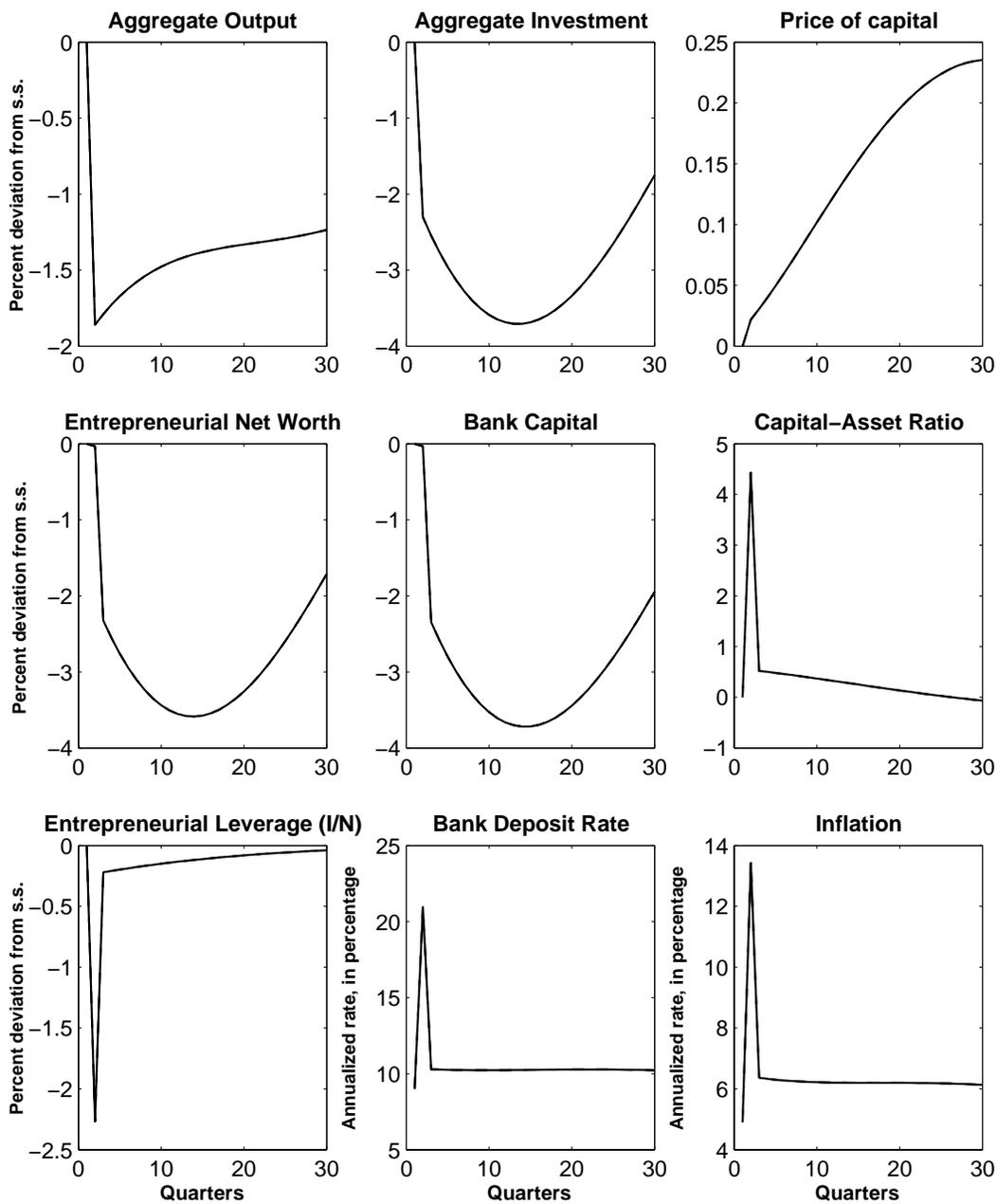


Figure 4. Contractionary Monetary Policy Shock: Extended Model

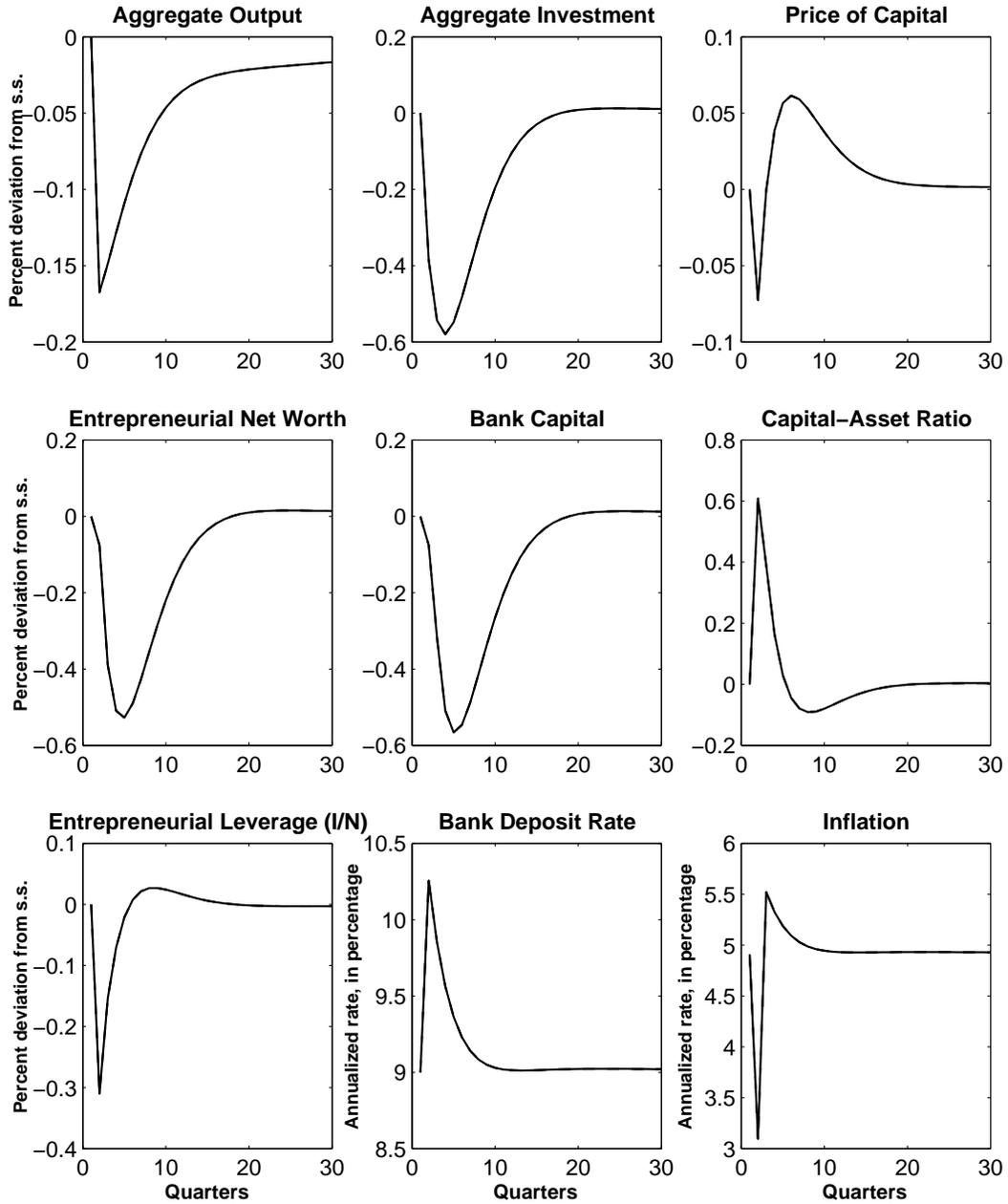


Figure 5. Contractionary Monetary Policy Shock: The Importance of Bank Capital

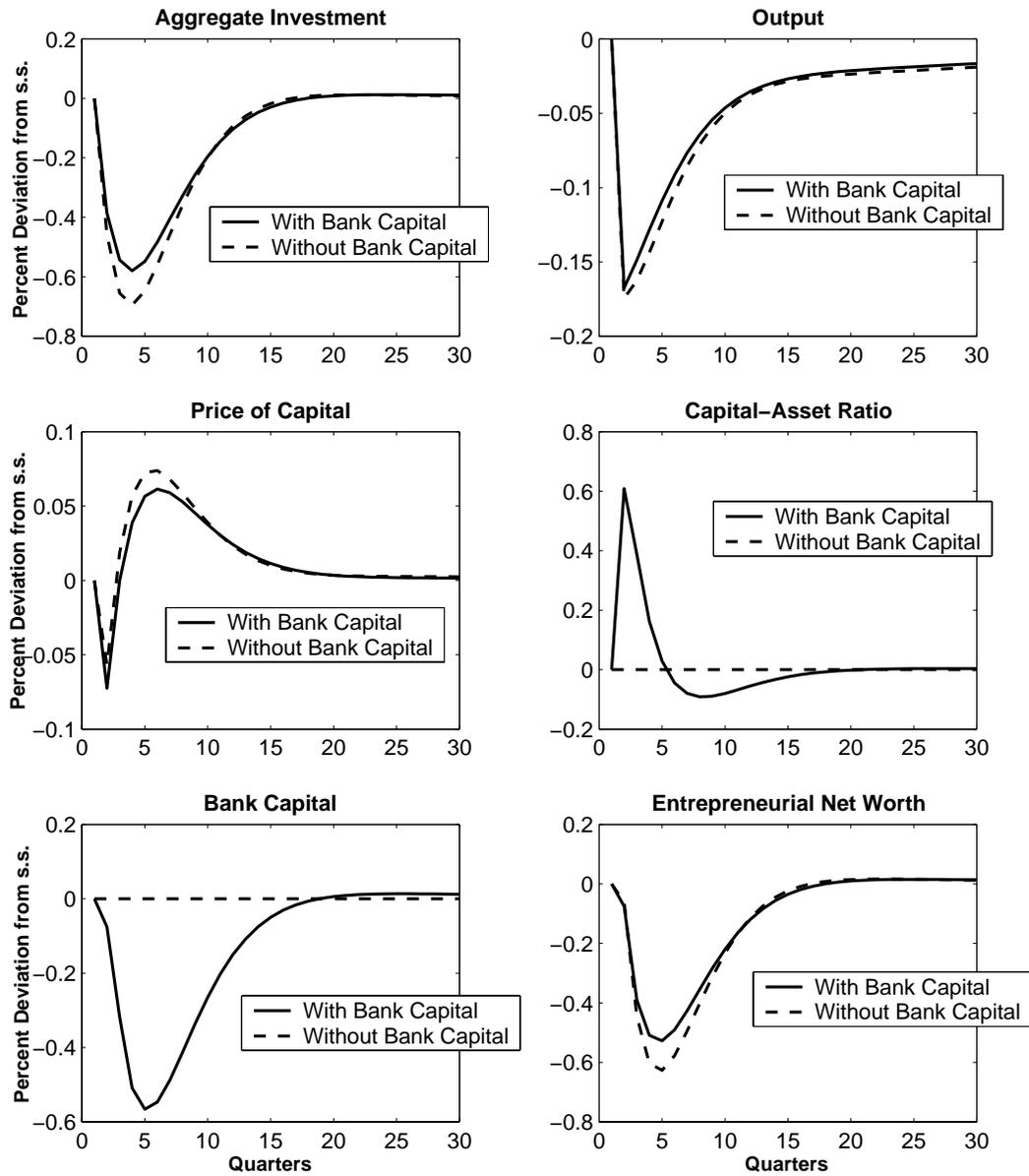


Figure 6. Contractionary Monetary Policy Shock: Sensitivity Analysis

