Capital Regulation and Monetary Policy with Fragile Banks*

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First draft: August 2009. This draft: July 2010

Abstract

We introduce banks, modeled along the lines of Diamond and Rajan (JoF 2000; JPE 2001), into a standard DSGE model and use this framework to study the role of banks in the transmission of shocks, the effects of monetary policy when banks are exposed to runs, and the interplay between monetary policy and Basel capital requirements. In equilibrium, bank leverage depends positively on the uncertainty of projects and on the bank's relationship lender skills, and negatively on short term interest rates. A monetary restriction reduces bank leverage and risk, while a productivity shock or asset price boom increases it. Risk-based capital requirements (as under Basel II) amplify the cycle; monetary policy can only partly offset this effect. The best policy combination includes mildly anticyclical minimum capital ratios and a response of monetary policy to asset prices or bank leverage.

Keywords: capital requirements, leverage, bank runs, macro-prudential policy, monetary policy.

*An earlier version of this paper appeared in 2009 as Kiel Working paper under the title "A Tale of Two Policies: Prudential Regulation and Monetary Policy with Fragile Banks". We are grateful to seminar participants at the Swiss National Bank, New York Fed, IMF, Georgetown University, Federal Reserve Board, Institute for Advanced Studies Vienna, Kiel Institute for the World Economy, National Bank of Hungary, European Central Bank, Goethe University Frankfurt, Oxford University for useful comments. Kiryl Khalmetski and Marc Schöfer provided excellent research assistance. We are the sole responsible for any errors and for the opinions expressed in this paper.

1 Introduction

The financial crisis is producing, among other consequences, a change in perception on the roles of financial regulation and monetary policy. The pre-crisis common wisdom sounded roughly like this. Capital requirements and other prudential instruments were supposed to ensure, at least with high probability, the solvency of individual banks, with the implicit tenet that stable banks would automatically translate into a stable financial system. On the other side, monetary policy should largely disregard financial matters and concentrate on pursuing price stability (a low and stable consumer price inflation) over some appropriate time horizon. The recent experience is changing this accepted wisdom in two ways. On the one hand, the traditional formal requirements for individual bank solvency (asset quality and adequate capital) are no longer seen as sufficient for systemic stability; regulators are increasingly called to adopt a *macro-prudential* approach (Borio [14], Lorenzoni[43], Morris and Shin [47]). On the other, some suggest that monetary policy should contribute to control systemic risks in the financial sector. This crisis has demonstrated that such risks can have disruptive implications for output and price stability, and there is increasing evidence that monetary policy influences the degree of riskiness of the financial sector (the "risk-taking channel" of Borio and Zhu [15], to which Maddaloni and Peydró Alcalde [44] and Altunbas et al. [4] have recently provided supporting evidence). These ideas suggest the possibility of interactions between the conduct of monetary policy and that of macroprudential regulation.

With this in mind, in this paper we aim at studying, in an integrated framework, how bank regulation and monetary policy interact in a macroeconomy that includes a fragile banking system. Our first goal is to propose a model that rigorously incorporates state-of-the art banking theory in a general equilibrium macro framework and also incorporates some key elements of financial fragility experienced in the recent crisis. In our model, banks provide liquidity to both depositors and entrepreneurs running a project. As in Diamond and Rajan ([26], [28]) they have special skills in redeploying the projects' assets in case of early liquidation. Uncertainty in the outcome of investment projects by firms injects risk in bank balance sheets. Banks are financed with deposits and capital and are exposed to *runs*, with a probability that increases with their degree of leverage. Our arguments apply equally well to traditional banks collecting (at least partially) uninsured deposits, and to other leveraged entities, financed through short-term debt like ABSs or commercial paper. The relationship between the bank and its "outside" financiers (depositors and capitalists) is disciplined by two incentives: depositors can run the bank, forcing early liquidation of the loan and depriving bank capital of its return; and the bank can withhold its special skills, forcing a costly liquidation of the loan. The desired capital ratio is determined by trading-off balance sheet risk with the ability to obtain higher returns for outside investors in "good states" (no run), which increase with the share of deposits in the bank's liability side.

Introducing these elements provides a characterization of financial sector that is, we think, more apt to interpret the recent experience than traditional "financial accelerator" formulations (like the classic Bernanke, Gertler and Gilchrist [9]), which, although pioneering the introduction of financial frictions into macro models, focus on the role of firms' collateral in the transmission of shocks rather than explicitly on banks. Endogenizing the bank capital structure also provides a natural way to study banking regulation in conjunction with monetary and other macro policies. Our model allows, inter alia, to study how capital regulation, and potentially also liquidity ratios and other prudential instruments, influence economic performance, collective welfare and the optimal monetary policy.

Other papers have examined optimal monetary policy design and bank regulation, with specific reference to the pro-cyclicality of capital requirements (Blum and Hellwig [13], and Cecchetti and Li [18]). Two main elements differentiate our work. First, the previous studies take capital requirements as given and study the optimal monetary policy response, while we consider their interaction and possible combinations. Second, in earlier studies the loan market and bank capital structure were specified exogenously or ad hoc, while we incorporate optimizing bank behavior explicitly. Gertler and Karadi [35] and Gertler and Kiyotaki [36] have recently proposed a model with micro-founded banks. In their work an asymmetric information problem between banks and uninformed investors is solved through the introduction of an incentive compatibility constraint, which leads to a relation between bank capital and external finance premia. Our approach to modelling the bank differs in that we allow for equilibrium bank runs. More importantly, their aim is to look at the effects of unconventional monetary policies, while we explore the interplay between (conventional) monetary policy and bank regulation. Their focus is more on crisis management, ours on crisis prevention.

From the solution of our banking model we find that the bank's optimal deposit ratio is positively related to: 1) the bank expected return on assets; 2) the uncertainty of the projects outcomes; 3) the banks' special skills in liquidating projects, and negatively related to 4) the return on bank deposits. These properties echo the main building blocks of the Diamond-Rajan banking model. The intuition, roughly speaking, is that increases in 1), 2) and 3) raise the return to outside bank investors of a unitary increase in deposits, the first by increasing the expected return in good states (no run), the second by reducing its cost in bad states (run), the third by increasing the expected return relative to the cost between the two states. A higher deposit rate reduces deposits from the supply side, because it increases, *ceteris paribus*, the probability of run. Inserting this banking core into a standard DSGE framework a number of results emerge. A monetary expansion or a positive productivity boom increase bank leverage and risk. The transmission from productivity changes to bank risk is stronger when the riskiness of the projects financed by the bank is low. Pro-cyclical capital requirements (akin to those implied by the Basel II internal ratings based approach) amplify the response of output and inflation to other shocks and may generate unstable dynamics. Monetary policy cannot neutralize this effect fully. Conversely, anti-cyclical ratios, requiring banks to build up capital buffers in more expansionary phases of the cycle, have the opposite effect. Finally, the optimal policy combination includes mildly anti-cyclical capital requirements (i.e., that require banks to build up capital in cyclical expansions) and a monetary policy rule that reacts to inflation and "leans-against-the-wind". Two alternative forms of "leaning" are examined: a positive response of the policy-determined interest rate to asset prices or to bank leverage.

The rest of the paper is as follows. Section 2 provides a telegraphic overview of the recent but rapidly growing literature merging banking into macro models. Section 3 describes the model. Section 4 characterizes the transmission mechanism. Section 5 examines the sensitivity to investment risk and the performance of leaning-against-the-wind monetary policy. Section 6 matches some properties of the calibrated model with data on the euro area and the US. Sections 7 discusses the effect of Basel capital ratios and how they affect the transmission mechanism. Section 8 examines the performance of alternative monetary policy rules combined with capital requirement regimes. Section 9 concludes.

2 Merging the Banking and the Macro Literatures

After the Great Crisis, a considerable discussion has developed on whether and how the macro literature should have embedded elements from the finance literature. Attempts to include financial frictions into macro model were pre-existing, but most of the them focused on the credit constraints faced alternatively by households and firms. Models of the financial accelerator family (see Bernanke and Gertler [35], Bernanke, Gertler and Gilchrist [9], Carlstrom and Fuerst [19], Christiano, Motto and Rostagno [21]) studied business cycle fluctuations generated by agency problems between firms and lenders, while models with collateral constraints in the lines of the Kiyotaki and Moore [42] had focused more on the impact of constraints on households borrowing on the macro dynamics[1]. After the crisis, however, particular as a result of the much greater emphasis placed on macro-prudential bank regulatory policies, it has become clear that standard macro models need extending to incorporate explicit micro-founded banking structures.

Recently, a few authors have moved in this direction, with purposes partially similar to ours. Those papers can be divided in three main categories, based on a classification pertaining to the finance literature. First, there are models that include banks facing a *single* moral hazard problem with the uninformed investors: to this category belong the contributions by Gertler and Karadi [35] and Gertler and Kiyotaki [36], with the latter also including an interbank market. In this case the moral hazard problem is dealt with by modeling incentive compatibility constraints of a dynamic nature. The second category includes models that embed a *dual* moral hazard problem on the lines of Diamond [24] and Holmström and Tirole [38]. To this category belong papers by Meh and Moran [45], Covas and Fujita [22], He and Krishnamurthy [37], Bunnermeier and Sannikov [17], of which the latter two use a continuos time structure. The third category includes models focusing on the industrial structure of the banking sector, following the Klein and Monti tradition: see for instance Gerali et al. [34], Angelini et al. [5], Darracq Paries et al. [23]. Many of those papers also explore the impact of regulatory capital requirement and in very few cases also the interaction with monetary policy.

None of the previously mentioned papers addresses the issue of bank runs. One of the main

[1] More recently Iacoviello [**?**] has studied models with collateral constraints on the housing market. There is also an extensive literature on the role of collateral constraints for over-borrowing and uninsurable idiosyncratic risk, which we do not report for brevity.

feature of the recent crisis, if not the most problematic, has been the dry up of liquidity, despite the fact that the shock to the housing market had occurred during a period a relatively expansionary monetary policies. Another major feature of the crisis was the occurrence of runs, though typically not on traditional deposits, but on other more volatile funding instruments issued by banks and their conduits, like REPOs and ABSs. For this reason, in our model we build on Diamond and Rajan [26], [28], models that include both moral hazard considerations and bank runs. While in this respect our model links up also with the literature on bank runs (see Diamond and Dybvig [25], Allen and Gale [1],[2],[3]), our analysis of the interplay between bank runs and liquidity does not lead to multiplicity of equilibria; hence we can study financial and macroeconomic stability issues, referring to currently existing monetary and bank regulatory policies, without introducing multiple equilibria, which would require making recourse to yet unexplored equilibrium-selecting instruments. The existence of equilibrium bank runs in our model leads to distributional effects, as in case of adverse shocks only uninformed investors are guaranteed a return, but does not affect the long run equilibrium[2].

Diamond and Rajan [27] provide a first attempt to integrate banks and bank runs in a monetary model. They do so in a two period economy model in which monetary policy is conducted by means of money supply and monetary non-neutrality is obtained via frictions on deposits. They find that monetary policy should inject money during contractionary phases. Our analysis is carried out in an infinite horizon model, hence it embodies a role for expectations. We also study optimal combinations of prudential regulation and monetary policy, and analyze the monetary transmission mechanism with fragile banks.

3 The Baseline Model

The starting point is a conventional DSGE model with nominal rigidities. There are five type of agents in this economy: households, financial intermediaries, non-financial good producers, capital producers and monopolistic firms. Financial intermediaries fund projects by raising money from depositors and bank capitalists. Projects are subject to an idiosyncratic shock, which introduces the

[2] Angeloni, Faia and Lo Duca [6] consider an extension of our model which includes the cost of runs. Such an additional feature does not alter the results obtained in this paper, but might lead to interesting long run dynamics and allows to study efficiency.

possibility of runs. As in Diamond and Rajan [26] [28] the bank capital structure is determined by bank managers, who act on behalf of outside investors (depositors and bank capitalists combined) by maximizing their overall return. Once the project's uncertain outcome is realized, bank capitalists claims the residual value after depositors are paid out. If the return on bank assets is low and the bank is not able to pay depositors in full there is a run on the bank, in which case the bank capital holders get zero while depositors get the market value of the liquidated loan. Finally, we assume that monopolistic firms in the production sector face quadratic adjustment costs on prices: such an assumption allows to generate non-neutral effects of monetary policy. Notice that alternative assumptions, such as adjustment costs on deposits or, generally speaking, sticky deposits, would be equivalent as they would not alter the type of interaction between monetary policy and banks as constructed in our model.

The following subsections provide more details on the macro model, which is rather standard, and especially on the banking sector.

3.1 Households

There is a continuum of identical households who consume, save and work. Households save by lending funds to the financial intermediaries, both in the form of deposits and bank capital. To allow aggregation within a representative agent framework we follow Gertler and Karadi [35] and assume that in every period a fraction γ of household members are bank capitalists and a fraction $(1-\gamma)$ are workers/depositors. Hence households also own financial intermediaries[3]. Bank capitalists remain engaged in their business activity next period with a probability θ, which is independent of history. This finite survival scheme is needed to avoid that bankers accumulate enough wealth to ease up the liquidity constraint. According to this structure a fraction $(1-\theta)$ of bank capitalists exit in every period. A corresponding fraction of workers become bank capitalists every period, so that the share of bank capitalists, γ, remains constant over time. Workers earn wages and return them to the household; similarly bank capitalists return their earnings to the households. However, bank capitalists earnings are not used for consumption but are given to the new bank capitalists and reinvested as bank capital. Consumption and investment decisions are made by the household,

[3] As in Gertler and Karadi [35] it is assumed that households hold deposits with financial intermediaries that they do not own.

pooling all available resources.

As mentioned before and following Diamond and Rajan [26] [28] the bank capital structure is determined by the bank managers, who maximize the returns of both depositors and bank capitalists. Bank managers are simply workers in the financial sector. Hence, household members can either work in the production sector or in the non-financial sector. We assume that the fraction of workers in the financial sector is negligible, hence their wage earnings are not included in the budget constraint.

Households maximize the following discounted sum of utilities:

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, N_t) \tag{1}$$

where C_t denotes aggregate consumption and N_t denotes labour hours. The workers in the production sector receive at the beginning of time t a real labour income $\frac{W_t}{P_t} N_t$.

Households save and invest in bank deposits and bank capital. Deposits, D_t, pay a gross nominal return R_t one period later. Finally, households are also the owners of both the monopolistic competitive sector, hence they receive nominal profits for an amount, Θ_t. The budget constraint reads as follows:

$$P_t C_t + T_t + D_{t+1} \leq W_t N_t + \Theta_t + R_t D_t \tag{2}$$

Note that the return from, and the investment in, bank capital do not appear in equation 2. The reason is that we have assumed, as explained later, that all returns on bank capital are reinvested every period.

Households choose the set of processes $\{C_t, N_t\}_{t=0}^{\infty}$ and deposits $\{D_{t+1}\}_{t=0}^{\infty}$, taking as given the set of processes $\{P_t, W_t, R_t\}_{t=0}^{\infty}$ and the initial value of deposits D_0 so as to maximize 1 subject to 2. The following optimality conditions hold:

$$\frac{W_t}{P_t} = -\frac{U_{n,t}}{U_{c,t}} \tag{3}$$

$$U_{c,t} = \beta E_t \{R_t U_{c,t+1}\} \tag{4}$$

Equation 3 gives the optimal choice for labour supply. Equation 4 gives the Euler condition with respect to deposits and government bonds. Optimality requires that the first order conditions and No-Ponzi game conditions are simultaneously satisfied.

3.2 Banks

There is in the economy a large number (L_t) of uncorrelated investment projects. The project lasts two periods and requires an initial investment. Each project's size is normalized to unity (think of one machine) and its price is Q_t. The projects require funds, which are provided by the bank. Likewise, banks have no internal funds, but receive finance from two classes of agents: holders of demand deposits and bank capitalists. Total bank loans (equal to the number of projects multiplied by their unit price) are equal to the sum of deposits (D_t) and bank capital, (BK_t). The aggregate bank balance sheet is:

$$Q_t L_t = D_t + BK_t \tag{5}$$

The capital structure (deposit share, equal to one minus the capital share) is determined by bank manager on behalf of the external financiers (depositors and bank capitalists). The manager's task is to find the capital structure that maximizes the combined expected return of depositors and capitalists, in exchange for a fee. Individual depositors are served sequentially and fully as they come to the bank for withdrawal; bank capitalists instead are rewarded pro-quota after all depositors are served. This payoff mechanism exposes the bank to runs, that occur when the return from the project is insufficient to reimburse all depositors. As soon as they realize that the payoff is insufficient they run the bank and force the liquidation of the project. The timing is as follows. At time t, the manager of bank k decides the optimal capital structure, expressed by the ratio of deposits to total loans, $d_{k,t} = \frac{D_{k,t}}{Q_{k,t}L_{k,t}}$, collects the funds, lends, and then the project is undertaken. At time $t+1$, the project's outcome is known and payments to depositors and bank capitalists (including the fee for the bank manager) are made, as discussed below. A new round of projects starts.

Generalizing Diamond and Rajan [26], [28], we assume that the return of each project for the bank is equal to an expected value, $R_{A,t}$, plus a random shock, for simplicity assumed to have a uniform density with dispersion h (the assumption yields a convenient closed form solution but is not essential; see Appendix 1 where we analyze the case of a normal distribution). Therefore, the project j outcome is $R_{A,t} + x_{j,t}$, where $x_{j,t}$ spans across the interval $[-h; h]$ with probability $\frac{1}{2h}$. We assume h to be constant across projects and time, but will run sensitivity analyses on its value.

Given our assumption of identical projects and banks, for notational convenience from now on we can omit project and bank subscripts. Until the end of this subsection we will omit time subscript as well.

Each project is financed by one bank. Our bank is a *relationship lender*: by lending it acquires a specialized non-sellable knowledge of the characteristics of the project. This knowledge determines an advantage in extracting value from it before the project is concluded, relative to other agents. Let the ratio of the value for the outsider (liquidation value) to the value for the bank be $0 < \lambda < 1$. Again we assume λ to be constant, but we will examine the sensitivity of the results to changes in its value.

Suppose the ex-post realization of x is negative, as depicted in Graph A at the end of the paper, point C, an consider how the payoffs of the three players are distributed depending on the ex-ante determined value of the deposit ratio d and the deposit rate R.

There are three cases.

Case A: Run for sure. The outcome of the project is too low to pay depositors. This happens if gross deposits (including interest) are located to the right-hand-side of C in the graph, where $R_A + x < Rd$. Payoffs in case of run are distributed as follows. Capitalists receive the leftover after depositors are served, so they get zero in this case. Depositors alone (without bank) would get only a fraction $\lambda(R_A + x)$ of the project's outcome; the remainder $(1 - \lambda)(R_A + x)$ is shared between depositors and the bank depending on their relative bargaining power. As Diamond and Rajan [26], we assume this extra return is split in half (other assumptions are possible without qualitative change in the results; see Appendix 3[4]). Therefore, depositors end up with

$$\frac{(1+\lambda)(R_A+x)}{2}$$

and the bank with

$$\frac{(1-\lambda)(R_A+x)}{2} \tag{6}$$

Note that we have assumed that bank runs do not destroy value *per se*, but only affect the distribution of returns. The model can easily be extended to include a specific deadweight loss from bank runs. Intuitively, the higher such loss, the lower the equilibrium deposit ratio.

Case B: Run only without the bank. The project outcome is high enough to allow depositors to be served if the project's value is extracted by the bank, but not otherwise. This happens if gross deposits (including interest) are located in the segment BC in the graph, i.e the range where $\lambda(R_A+x) < Rd \leq (R_A+x)$. In this case, the capitalists alone cannot avoid the run, but with the bank they can. So depositors are paid in full, Rd, and the remainder is split in half between the banker and the capitalists, each getting $\frac{R_A+x-Rd}{2}$. Total payment to outsiders is $\frac{R_A+x+Rd}{2}$.

Case C: No run for sure. The project's outcome is high enough to allow all depositors to be served, with or without the bank's participation. This happens in the zone AB, where $Rd \leq \lambda(R_A+x)$. Depositors get Rd. However, unlike in the previous case, now the capitalists have a higher bargaining power because they could decide to liquidate the project alone and pay the depositors in full, getting $\lambda(R_A+x)-Rd$; this is thus a lower threshold for them. The banker can extract $(R_A+x)-Rd$, and again we assume that the capitalist and the bank split this extra return in half. Therefore, the bank gets:

$$\frac{[(R_A+x)-Rd]-[\lambda(R_A+x)-Rd]}{2} = \frac{(1-\lambda)(R_A+x)}{2}$$

This is less than what the capitalist gets. Total payment to outsiders is:

[4]Depositors and bank managers have equal bargaining power because neither can appropriate the extra rent without help from the other. An alternative assumption to the hypothesis of equal bargaining power is analysed in Appendix 3. Diamond and Rajan [26] mention also another case in which the depositors, after appropriating the project, bargain directly with the entrepreneur running the project. If the entrepreneur retains half of the rent, the result is obviously unchanged. If not, the resulting equilibrium is more tilted towards a high level of deposits, because depositors lose less in case of bank run.

$$\frac{(1+\lambda)(R_A+x)}{2}$$

We can now write the expected value of total payments to outsiders as follows:

$$\frac{1}{2h}\int_{-h}^{Rd-R_A}\frac{(1+\lambda)(R_A+x)}{2}dx+\frac{1}{2h}\int_{Rd-R_A}^{\frac{Rd}{\lambda}-R_A}\frac{(R_A+x)+Rd}{2}dx+ \tag{7}$$

$$+\quad\frac{1}{2h}\int_{\frac{Rd}{\lambda}-R_A}^{h}\frac{(1+\lambda)(R_A+x)}{2}dx$$

The three terms express the payoffs to outsiders in the three cases described above, in order. The banker´s problem is to maximize expected total payments to outsiders by choosing the suitable value of d.

Proposition 1. The value of d_t that maximizes equation 7 is comprised in the interval $\lambda\frac{R_A+h}{R}<d<\frac{R_A+h}{R}$.

Proof. See Appendix 1.

In this zone, the third integral in the equation vanishes and the expression reduces to

$$\frac{1}{2h}\int_{-h}^{Rd-R_A}\frac{(1+\lambda)(R_A+x)}{2}dx+\frac{1}{2h}\int_{Rd-R_A}^{h}\frac{(R_A+x)+Rd}{2}dx \tag{8}$$

Consider equation 8 in detail. A marginal increase in the deposit ratio has three effects. First, it increases the range of x where a run occurs, by raising the upper limit of the first integral; this effect increases the overall return to outsiders by $\frac{1}{2h}\left(\frac{1+\lambda}{2}Rd\right)R$. Second, it decreases the range of x where a run does not occur, by raising the lower limit of the second integral; the effect of this on the return to outsiders is negative and equal to $-\frac{1}{2h}R^2d$. Third, it increases the return to outsiders for each value of x where a run does not occurs; this effect is $\frac{1}{2h}\left(\int_{Rd-R_A}^{h}\frac{1}{2}dx\right)R=\frac{1}{2h}\left(\frac{h-Rd+R_A}{2}\right)R$. Equating to zero the sum of the three effects and solving for d yields the following solution for the level of deposits for each unit of loans

$$d = \frac{1}{R}\frac{R_A + h}{2 - \lambda}. \tag{9}$$

Since the second derivative is negative, this is the optimal value of d.

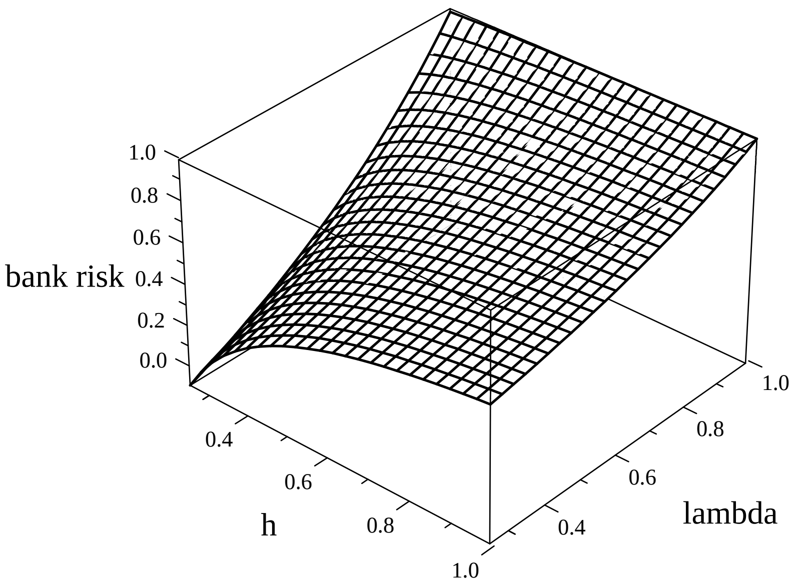
The optimal deposit ratio depends positively on h, λ and R_A, and negatively on R. An increase of R reduces deposits because it increases the probability of run. Moreover, an increase in R_A raises the marginal return in the no-run case (the third effect just mentioned), while it does not affect the other two effects, hence it raises d. An increase in λ reduces the cost in the run case (first effect), while not affecting the others, so it raises d. The effect of h is more tricky. At first sight it would seem that an increase in the dispersion of the project outcomes, moving the extreme values of the distribution both upwards and downwards, should be symmetric and have no effect. But this is not the case. When h increases, the probability of each given project outcome $\frac{1}{2h}$ falls. Hence the expected loss stemming from the change in the relative probabilities (sum of the first two effects) falls, but the marginal gain in the no-run case (third term) does not, because the upper limit increases. The marginal effect is $\frac{R}{2}$, because depositors get the full return, but half is lost by the capitalist to the banker. Hence, the increase of h has on d a positive effect, as R_A.

3.2.1 A measure of bank fragility

A natural measure of bank riskiness is the probability of a run occurring. This can be written as:

$$z_t = \frac{1}{2h}\int_{-h}^{Rd-R_A} dx = \frac{1}{2}\left(1 - \frac{R_A - Rd}{h}\right) = \frac{1}{2} - \frac{R_A(1-\lambda) - h}{2h(2-\lambda)} \tag{10}$$

The chart below shows the shape of the last function in 10 for $R_A = 1.03$). Note that for low values of λ and h, $\frac{R_A+h}{2-\lambda}$ falls below $R_A + h$ and the marginal equilibrium condition 9 and the last equality of 10 cease to hold. Deposits can never fall below the level where a run becomes impossible. Some degree of bank risk is always optimal in this model.



3.2.2 Aggregation

In the aggregate, the amount invested in every period is $Q_t L_t$. The total amount of deposits in the economy is

$$D_t = \frac{Q_t L_t}{R_t} \frac{R_{A,t} + h}{2 - \lambda} \tag{11}$$

and the bank's optimal capital is:

$$BK_t = (1 - \frac{1}{R_t} \frac{R_{A,t} + h}{2 - \lambda}) Q_t L_t \tag{12}$$

Projects are financed by the intermediary for an amount:

$$Q_t L_t = Q_t K_t \tag{13}$$

The above expressions suggest that following an increase in R_t the optimal amount of bank capital increases on impact (for given R_A). The effect of other factors in general equilibrium is more complex, depending on several counterbalancing factors affecting R_A and R, as the later results will show.

3.2.3 Accumulation of bank capital

Equation 9 is the level of bank capital desired by the bank manager, for any given level of investment, Q_tL_t and interest rate structure (R_t, $R_{A,t}$). We assume that bank capital is provided by the bank capitalist. After remunerating depositors and paying the competitive fee to the bank manager, a return accrues to the bank capitalist, and this is reinvested in the bank as follows:

$$BK_t = \theta[BK_{t-1} + RTK_tQ_tK_t] \tag{14}$$

where RTK_t is the unitary return to the capitalist. The parameter θ is a decay rate, given by the bank survival rate already discussed. RTK_t can be derived from equation 8 as follows:

$$RTK_t = \frac{1}{2h}\int_{R_td_t-R_{A,t}}^{h} \frac{(R_{A,t}+x)-R_td_t}{2}dx_t = \frac{(R_{A,t}+h-R_td_t)^2}{8h} \tag{15}$$

Note that this expression considers only the no-run state because if a run occurs the capitalist receives no return. The accumulation of bank capital obtained substituting 15 into 14:

$$BK_t = \theta[BK_{t-1} + \frac{(R_{A,t}+h-R_td_t)^2}{8h}Q_tK_t] \tag{16}$$

3.3 Producers

Each firm i has monopolistic power in the production of its own variety and therefore has leverage in setting the price. In changing prices it faces a quadratic cost equal to $\frac{\vartheta}{2}(\frac{P_t(i)}{P_{t-1}(i)} - 1)^2$, where the parameter ϑ measures the degree of nominal price rigidity. The higher ϑ the more sluggish is the adjustment of nominal prices. In the particular case of $\vartheta = 0$, prices are flexible. Each firm assembles labour (supplied by the workers) and (finished) entrepreneurial capital to operate a constant return to scale production function for the variety i of the intermediate good:

$$Y_t(i) = A_tF(N_t(i), K_t(i)) \tag{17}$$

Each monopolistic firm chooses a sequence $\{K_t(i), L_t(i), P_t(i)\}$, taking nominal wage rates W_t and the rental rate of capital Z_t, as given, in order to maximize expected discounted nominal profits:

$$E_0\{\sum_{t=0}^{\infty}\Lambda_{0,t}[P_t(i)Y_t(i) - (W_tN_t(i) + Z_tK_t(i)) - \frac{\vartheta}{2}\left[\frac{P_t(i)}{P_{t-1}(i)} - 1\right]^2 P_t]\} \tag{18}$$

subject to the constraint $A_tF_t(\bullet) \leq Y_t(i)$, where $\Lambda_{0,t}$ is the households' stochastic discount factor.

Let's denote by $\{mc_t\}_{t=0}^{\infty}$ the sequence of Lagrange multipliers on the above demand constraint, and by $\tilde{p}_t \equiv \frac{P_t(i)}{P_t}$ the relative price of variety i. The first order conditions of the above problem read:

$$\frac{W_t}{P_t(i)} = mc_tA_tF_{n,t} \tag{19}$$

$$\frac{Z_t}{P_t(i)} = mc_tA_tF_{k,t} \tag{20}$$

$$\begin{aligned} 0 \quad = \quad & U_{c,t}Y_t\tilde{p}_t^{-\varepsilon}((1-\varepsilon) + \varepsilon mc_t) - U_{c,t}\vartheta\left[\pi_t\frac{\tilde{p}_t}{\tilde{p}_{t-1}} - 1\right]\frac{\pi_t}{\tilde{p}_{t-1}} + \\ & +\vartheta E_t\{U_{c,t}\left[\pi_{t+1}\frac{p_{t+1}}{p_t} - 1\right]\pi_{t+1}\frac{\tilde{p}_{t+1}}{\tilde{p}_t^2}\} \end{aligned} \tag{21}$$

where $F_{n,t}$ is the marginal product of labour, $F_{k,t}$ the marginal product of capital and $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross aggregate inflation rate (its steady state value, π, is equal to 1). Notice that all firms employ an identical capital/labour ratio in equilibrium, so individual prices are all equal in equilibrium. The Lagrange multiplier mc_t plays the role of the real marginal cost of production. In a symmetric equilibrium $\tilde{p}_t = 1$. This allows to rewrite equation 21 in the following form:

$$\begin{aligned} U_{c,t}(\pi_t - 1)\pi_t \quad = \quad & \beta E_t\{U_{c,t+1}(\pi_{t+1} - 1)\pi_{t+1}\} + \\ & +U_{c,t}A_tF_t(\bullet)\frac{\varepsilon}{\vartheta}(mc_t - \frac{\varepsilon - 1}{\varepsilon}) \end{aligned} \tag{22}$$

The above equation is a non-linear forward looking New-Keynesian Phillips curve, in which deviations of the real marginal cost from its desired steady state value are the driving force of inflation.[5]

3.3.1 Capital Producers

A competitive sector of capital producers combines investment (expressed in the same composite as the final good, hence with price P_t) and existing capital stock to produce new capital goods. This activity entails physical adjustment costs. The corresponding CRS production function is $\phi(\frac{I_t}{K_t})K_t$, so that capital accumulation obeys:

$$K_{t+1} = (1-\delta)K_t + \phi(\frac{I_t}{K_t})K_t \tag{23}$$

where $\phi(\bullet)$ is increasing and convex.

Define Q_t as the re-sell price of the capital good. Capital producers maximize profits $Q_t\phi(\frac{I_t}{K_t})K_t - P_tI_t$, implying the following first order condition:

$$Q_t\phi'(\frac{I_t}{K_t}) = P_t \tag{24}$$

The gross (nominal) return from holding one unit of capital between t and $t+1$ is composed of the rental rate plus the re-sell price of capital (net of depreciation and physical adjustment costs):

$$Y_t^k \equiv Z_t + Q_t((1-\delta) - \phi\prime(\frac{I_t}{K_t})\frac{I_t}{K_t} + \phi(\frac{I_t}{K_t})) \tag{25}$$

The gross (real) return from holding a unit of capital between t and $t+1$ is equalized in equilibrium to the gross (real) return that the banks receive for their loan services, $R_{A,t+1}$:

$$\frac{R_{A,t+1}}{\pi_{t+1}} \equiv \frac{Y_{t+1}^k}{Q_t} \tag{26}$$

3.4 Goods Market Clearing

Equilibrium in the final good market requires that the production of the final good equals the sum of private consumption by households, investment, public spending, and the resource costs that

[5] Woodford [55].

originate from the adjustment of prices:

$$Y_t = C_t + I_t + G_t + \frac{\vartheta}{2}(\pi_t - 1)^2 \tag{27}$$

In the above equation, G_t is government consumption of the final good which evolves exogenously and is assumed to be financed by lump sum taxes.

3.5 Monetary Policy

We assume that monetary policy is conducted by means of an interest rate reaction function of this form:

$$\begin{aligned} \ln\left(\frac{R_t}{R}\right) &= (1-\phi_r)\left[\phi_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \phi_y \ln\left(\frac{Y_t}{Y}\right) + \phi_q \ln\left(\frac{Q_t}{Q}\right) + \phi_d \ln\Delta\left(\frac{d_t}{d}\right)\right] \\ &\quad + \phi_r \ln\left(\frac{R_{t-1}}{R}\right) \end{aligned} \tag{28}$$

All variables are deviations from the target or steady state (symbols without time subscript). Note that the reaction function includes two alternative terms that express leaning-against-the-wind behavior, respectively a reaction to asset prices (Q_t) or to the change of the deposit ratio (d_t). We will compare policy rules of this form, characterized by different parameter sets $\{\phi_\pi, \phi_y, \phi_q, \phi_d, \phi_r\}$. We solve the model by computing a second order approximation of the policy functions around the non-stochastic steady state.

3.6 Parameter values

Household preferences and production. The time unit is the quarter. The utility function of households is $U(C_t, N_t) = \frac{C_t^{1-\sigma}-1}{1-\sigma} + \nu \log(1-N_t)$, with $\sigma = 2$, as in most real business cycle literature. We set ν set equal to 3, chosen in such a way to generate a steady-state level of employment $N \approx 0.3$. We set the discount factor $\beta = 0.995$, so that the annual real interest rate is equal to 1%. We assume a Cobb-Douglas production function $F(\bullet) = K_t^\alpha (N_t)^{1-\alpha}$, with $\alpha = 0.3$. The quarterly aggregate capital depreciation rate δ is 0.025, the elasticity of substitution between varieties 6. The adjustment cost parameter is set so that the volatility of investment is larger than the volatility of output, consistently with empirical evidence: this implies an elasticity of asset prices to investment of 2.

In order to parameterize the degree of price stickiness ϑ, we observe that by log-linearizing equation 22 we can obtain an elasticity of inflation to real marginal cost (normalized by the steady-state level of output)[6] that takes the form $\frac{\varepsilon-1}{\vartheta}$. This allows a direct comparison with empirical studies on the New-Keynesian Phillips curve such as Gali and Gertler [33] and Sbordone [51] using Calvo-Yun approach. In those studies, the slope coefficient of the log-linear Phillips curve can be expressed as $\frac{(1-\hat{\vartheta})(1-\beta\hat{\vartheta})}{\hat{\vartheta}}$, where $\hat{\vartheta}$ is the probability of not resetting the price in any given period in the Calvo-Yun model. For any given values of ε, which entails a choice of the steady state level of the markup, we can thus build a mapping between the frequency of price adjustment in the Calvo-Yun model $\frac{1}{1-\hat{\vartheta}}$ and the degree of price stickiness ϑ in the Rotemberg setup. The recent New Keynesian literature has usually considered a frequency of price adjustment of four quarters as realistic. Recently, Bils and Klenow [10] have argued that the observed frequency of price adjustment in the US is higher, in the order of two quarters. As a benchmark, we parameterize $\frac{1}{1-\hat{\vartheta}} = 4$, which implies $\hat{\vartheta} = 0.75$. Given $\varepsilon = 6$, the resulting stickiness parameter satisfies $\vartheta = \frac{Y\hat{\vartheta}(\varepsilon-1)}{(1-\hat{\vartheta})(1-\beta\hat{\vartheta})} \approx 30$, where Y is steady-state output.

Banks. To calibrate h we have calculated the average dispersion of corporate returns from the data constructed by Bloom et al. [12] (we are grateful to Nick Bloom for giving us access to his data), which is around 0.3, and multiplied this by the square root of 3, the ratio of the maximum deviation to the standard deviation of a uniform distribution. The result is 0.5. We set the value of h slightly lower, at 0.45, a number that yields a more accurate estimates of the steady state values of the bank deposit ratio[7], and then run sensitivity analyses above and below this value.

One way to interpret λ is to see it as the ratio of two present values of the project, the first at the interest rate applied to firms' external finance, the second discounted at the bank internal finance rate (the money market rate). A benchmark estimate can be obtained by taking the historical ratio

[6] To produce a slope coefficient directly comparable to the empirical literature on the New Keynesian Phillips curve this elasticity needs to be normalized by the level of output when the price adjustement cost factor is not explicitly proportional to output, as assumed here.

[7] The bank capital accumulation equation 14, once we substitute in the optimal deposit ratio 8, and the return accruing to the bank capitalist 15, yields a quadratic equation in R_A. Solving the quadratic equation for given values of the parameters, one obtains a root for R_A equal to 1.03 (3 percent on a quarterly basis). The corresponding value of d is 95 percent, and bk is 5 percent. Notice that the bank capital accumulation equation includes the money that households transfer in every period to new bankers, given by a fraction of the value of the project: $\phi Q_t K_t$. The steady state value that helps to pin down the return on asset, R_A, is 0.075. Since such term is negligible we have omitted that in the dynamic.

between the money market rate and the lending rate. In the US over the last 20 years, based on 30-year mortgage loans, this ratio has been around 3 percent. This leads to a value of λ around 0.6. In the empirical analyses we have chosen 0.45 and then run sensitivity analyses above and below this value. Finally we parametrize the survival rate of banks at 0.97.

Note that, in principle, h and λ could be considered endogenous to the state of the economy. Recent work by Bloom ([11], [12]) has shown that the dispersion of corporate returns is anticyclical: cyclical slowdowns are systematically associated with a higher variance returns (actually, higher uncertainty of corporate returns *leads* business cycle downturns). The link between h and the cycle is a further element that could be added into our framework. In this paper we have used a fixed h throughout, and done sensitivity analysis.

Shocks. Total factor productivity is assumed to evolve as:

$$A_t = A_{t-1}^{\rho_\alpha} \exp(\varepsilon_t^\alpha) \tag{29}$$

where the steady-state value A is normalized to unity (which in turn implies $\omega_m = 1$) and where ε_t^α is an i.i.d. shock with standard deviation σ_α. In line with the real business cycle literature, we set $\rho_\alpha = 0.95$ and $\sigma_\alpha = 0.056$. Log-government consumption is assumed to evolve according to the following process:

$$\ln(\frac{G_t}{G}) = \rho_g \ln(\frac{G_{t-1}}{G}) + \varepsilon_t^g$$

where G is the steady-state share of government consumption (set in such a way that $\frac{G}{Y} = 0.25$) and ε_t^g is an i.i.d. shock with standard deviation σ_g. We follow the empirical evidence for the U.S. in Perotti [48] and set $\sigma_g = 0.0074$ and $\rho_g = 0.9$.

We introduce a monetary policy shock as an additive disturbance to the interest rate set through the monetary policy rule. The monetary policy shock is assumed to have moderate persistence (0.3 in the benchmark model); the low persistence of this shock is demonstrated e.g. by Rudebusch [50]. Following evidence by Angeloni, Faia and Lo Duca [6], and consistently with other empirical results for US and Europe, the standard deviations of the shocks is set to 0.006.

4 Transmission Channels

We first look at the responses to three shocks, one at a time, with parameters kept at their benchmark values: a one-time (total factor) productivity rise; a (moderately persistent) monetary restriction (persistence parameter 0.2); a one-time positive shock to the marginal return on capital (MRK), interpreted as a positive asset price shock. The latter shock, in particular, will be useful later when we will analyse monetary rules including a response to asset prices.

As it is standard in DSGE models with nominal rigidities, a positive *productivity shock* (figure 1) reduces inflation and increases output. The increase in productivity also brings about an increase in capital and investment. The ensuing increase in the asset price reduces the return on projects, $R_{A,t}$. The policy-driven short term interest rate R_t as the monetary authority reacts to the fall in inflation by means of a Taylor rule. The lower interest rates raise deposits and tilt the composition of the bank balance sheet towards higher leverage and risk.

In the *monetary shock* (figure 2) both inflation and output drop on impact, as in all standard models, with a corresponding fall in investment and Tobin's Q. The reduction in the asset price induces an increase in the return to capital, $R_{A,t}$. Also the spread between $R_{A,t}$ and R_t rises, but this is sensitive to parameter values – generally speaking, with a persistent shock or with interest rate smoothing, the spread tends to rise after a monetary restriction. Banks lose deposits and replace them with capital, leading to a less risky balance sheet composition; bank riskiness drops on impact – a "risk taking channel" of monetary policy operating in reverse.

Figure 3 shows the response of the selected variables to a positive *asset market shock,* which is modeled as an AR(1) shock to the return to capital. The increase in $R_{A,t}$ brings about an increase in investment. As a consequence of the increase in capital, output rises. The interest rate R_t broadly follows the dynamics of inflation. Bank risk declines, despite the high deposit ratio, due to the rise in the spread between $R_{A,t}$ and $R_t d_t$.

The above results together suggest that the co-movements of bank risk on one side, and interest rates and output on the other, depend on the nature of the shock. Higher policy-driven interest rates lead to lower bank risk, but not if there is a concurrent investment boom, for example generated by asset market exuberance. In this case banks become more risky in spite of higher policy rates.

To examine how banks affect the transmission, we compare two models, one with benchmark parameters, the other obtained setting $\lambda = 0.65$. A higher value of λ means that banks lose some of their advantage as relationship lenders. In figure 4, constructed assuming a TFP shock, the response from the standard model with banks is shown with a solid line, that from the model with higher λ with a dashed line. We can see that a low λ amplifies the short run expansionary effect on output. The reason is that the decline in ROA is larger in the short run. ROA is the key transmission variable from the banking to the real sector in our model.

5 Sensitivity to Key Parameters

5.1 Entrepreneurial risk

Entrepreneurial risk is distinct from bank risk: the first is measured by the parameter h, while the second depends endogenously on the bank capital structure. The two are linked, however: a higher h tends to increase the bank leverage and the probability of run on the bank , as one can see in equation 10 and the chart attached to it. Moreover, h also affects the response of the bank capital structure and risk to all other shocks.

Figures 5 and 6 report the responses to a TFP and a monetary shock respectively, with values of h equal to 0.45, the baseline, and 0.65, an alternative in which the entrepreneurial risk is higher.

Under the positive productivity shock, the short run response of output, capital, credit and investment is stronger if the value of h is lower. This highlights a self-reinforcing mechanism that may operate in "exuberant" phases: positive productivity shocks are more expansionary if the perception of investment risk is low.

Under a monetary restriction, on the contrary, the business cycle response is amplified in the high risk case; we have a bigger drop in output, investment and capital, together with a sharper fall in bank leverage. This is due to the fact that the downward effect of a given change in the interest rate on the deposit ratio is stronger when h is high (see equation 9), hence in presence of a stronger need for bank capital $R_{A,t}$ rises more on impact and the transmission to investment and output is higher.

By contrast, however, under a monetary shock the impact on bank riskiness is *smaller* when entrepreneurial risk is *higher* (a high h dampens the stronger increase in R_A in equation 10). This means that the risk taking channel of monetary policy impacts *more strongly* when the ex-ante uncertainty of projects is *low* (this effect involving two factors, h and the interest rate, should not be confused with the fact that bank risk increases when entrepreneurial risk h rises, as we have already noted). This observation connects with the earlier one concerning "exuberant" states; in these situations, an overly expansionary monetary policy tends to have particularly strong effects on bank leverage, exacerbating the increase of bank risk. Since the empirical evidence shows that entrepreneurial risk tends to be anti-cyclical, we conclude that the strength of the risk taking channel depends on the cyclical position. An expansionary monetary policy when the economy is strong increases bank risk by more than the same policy when the economy is weak.

5.2 Leaning against the wind

Figure 7 compares the benchmark monetary policy rule with two strategies in which the interest rate reacts also to asset prices (more precisely Tobin's Q, with a coefficient of 0.5) or alternatively to bank leverage (the change in the deposit ratio, with the same coefficient). We regard these as alternative options of using monetary policy (also) to control risks in the financial sector by leaning-against-the-wind in financial markets. Comparing these alternatives can contribute new elements to the old debate on whether monetary policy should react to expected inflation only (see Bernanke and Gertler [7]) or to asset prices as well (Cecchetti, Genberg, Lipsky and Whadwani [20]). Since one argument in that debate was that responding to asset prices would inject volatility in the economy, it is interesting to look at an alternative measure based on bank balance sheets, that should be empirically more stable.

The figure is constructed assuming an asset price shock. As one can see, the two strategies give mixed results. The rule that reacts to Tobin Q is successful in stabilizing inflation and to some extent also output, but on bank risk and the deposit ration the result is less clear. Reacting to leverage instead does not seem to improve the performance relative to a standard Taylor rule, and in some cases (on output and inflation for example) the performance is actually worse. All in all, the results speak in favor of responding to asset prices, not leverage. But this result is obtained under a single shock only. As we shall se later, using a broader set of calibrated shocks tends to tilt the balance in favor of responding to leverage in some cases.

6 Matching the Data

Before introducing regulatory bank capital requirements and turning to the analysis of optimal policy it is useful to compare the quantitative properties of our model with the data. We do so by comparing a series of statistics (standard deviation and first order autocorrelation) generated by our model with the data equivalent.

We look at data for both the US and the euro area for the following variables: output, consumption, investment, employment, the deposit rate, the return on assets, the deposit ratio, and bank riskiness. All data are quarterly and seasonally adjusted where necessary. Euro area aggregates are reconstructed backward using the available subsets of countries, with the multiplicative method. Data samples vary according to availability; for the euro area, national accounts data were reconstructed back since 1963, while most banking variables start in the 1970s or early 1980s. For the US, the starting date is generally 1970 or, for interest rates, the late 1950s. All data series end with the most recent available quarter, normally 2010Q1. Notice that we have included the crisis period since our model permits the existence of bank runs in equilibrium, though our data samples are evidently referring to normal (non crisis) market situations.

Deposit rates for the US are average rates on all deposits included in M2; for the euro area, average rates on short and long term deposits. Lending rates for the US are proxied by the 6-month commercial paper rate, for the euro area by the average rate on loans to households and non-financial corporations. To proxy the deposit ratio, which in the model measures bank balance sheet risk, departing from common practice we use the ratio total bank assets to total deposits. As argued in Angeloni, Faia and Lo Duca [6], this is a better proxy of balance sheet risk when the coverage of deposit insurance is large. Insured deposits have increasingly acquired, in recent years, the nature of stable source of funding for banks, in contrast with other more volatile instruments (REPOs, short term ABCP, structured products, etc.). The ratio of total assets to total deposits is a measure of the incidence of these volatile sources of funding in the bank balance sheet. Finally, bank risk is measured by aggregate default probability measures provided by Moody's KMV.

Our main sources of data were, for the US, the St. Louis Fed website and for the euro area the ECB. All variables are detrended before calculating standard deviations and autocorrelation, using a Hodrick-Prescott filter.

The model equivalent statistics are computed by considering the three fundamental shocks to productivity, government expenditure and monetary policy. Shocks have been parametrized as described in the calibration section. Standard deviations and first order autocorrelation, for both the model and the data, are summarized in table 1. For the comparison we have standardized the volatility of output to 1 percent, and we have computed the standard deviations for the other variables relative to that of output (both in the model and in the data). Autocorrelation of all variables are instead presented with their actual size.

Table 1. Statistics in the model and the data

Variable	Model		Euro area		US	
	St. Dev.	Auto-corr	St. Dev.	Auto-corr	St. Dev.	Auto-corr
Output (standardized)	1	0.80	1	0.90	1	0.87
Consumption	1.13	0.95	0.66	0.79	0.84	0.97
Investment	3.29	0.35	2.58	0.88	4.12	0.90
Employment	0.72	0.29	0.80	0.94	0.88	0.92
Deposit rate	0.45	0.98	0.30	0.90	0.45	0.57
Lending rate (R_A)	0.43	0.78	0.73	0.90	0.45	0.59
Deposit ratio	1.07	0.98	1.15	0.99	1.83	0.83
Bank riskiness	0.79	0.78	0.30	0.85	0.18	0.26

On the side of the real variables, the model broadly captures the volatility of investment, therefore showing that this type of credit frictions can explain well the path of investment. Output persistence is also matched well by the model. A less than perfect matching exists for the persistence of consumption and employment, but that is explained by the fact that the real side of model does not contain any friction on consumption and the labor market.

On the side of the banking variables the volatility and the persistence of the deposit ratio, a crucial variable in our model, matches both the values for the euro area and the US. The volatilities of the deposit and the loan rate also match the corresponding volatilities in the US economy, while the persistence of the same variables is closer to the ones observed for the euro area. There seem to be less persistence in the banking variables in the US, a fact that may be justified by the stronger competition of US banking markets. As for the measure of bank riskiness the model seems to overestimate the volatility: this might be due to the fact that the data sample goes back in time, including periods in which the banking system was stable, both in the euro area and the US.

7 Introducing Bank Capital Requirements

Capital regulation takes the form of a minimum state contingent ratio between banking capital, BK_t, and total bank loan exposure, Q_tK_t. The minimum regulatory capital ratio in the model is given by following iso-elastic function:

$$bk_t^{MIN} \equiv \frac{BK_t^{MIN}}{Q_tK_t} = const + b_0^c \left(\frac{Y_t}{Y_{SS}}\right)^{b_1^c} \tag{30}$$

In Appendix 2 we show that equation 30 mimics very well the minimum capital requirement implied by the internal ratings based (IRB) approach of Basel II, for appropriate values of the constant, b_0^c and b_1^c. Specifically, a negative value of b_1^c implies that the minimum capital ratio decreases with the output gap; since the average riskiness of bank loans tends to be negatively correlated with the cycle (see Appendix 2 for estimates), one can calibrate b_1^c so that equation 30 reproduces, for each value of the output gap, the capital requirement under the IRB approach, in which the minimum capital ratio increases with the riskiness of the bank's loan portfolio. For $b_1^c = 0$, equation 30 reproduces the Basel I regime, in which the capital ratio is fixed [8]. Setting positive value of b_1^c one can study the implications of a hypothetical regime that, following the current discussions about reforming Basel II, requires banks to accumulate extra capital buffers when the economy is booming.

In presence of a minimum capital ratio, banks determine their *actual* capital by optimally setting the risk that, after the stochastic component of their asset side is realized, their capital buffer net of losses may fall below the required ratio. The distinction between *actual*, *regulatory* and *economic* capital (the latter being the optimal capital set by the bank in absence of regulation) is analyzed by Elizaldea and Repullo [49] in the context of a partial equilibrium banking model.

In our framework, the actual bank capital ratio under regulation is determined extending equation 7 as follows

[8] In fact, a small degree of pro-cyclicality existed also in Basel I, due to accounting conventions and other factors.

$$\frac{1}{2h}\int_{-h}^{R_t d_t + bk_t^{MIN} - R_{A,t}} \frac{(1+\lambda)(R_{A,t}+x_{j,t})}{2} dx_{j,t} + \frac{1}{2h}\int_{R_t d_t + bk_t^{MIN} - R_{A,t}}^{\frac{R_t d_t + bk_t^{MIN}}{\lambda} - R_{A,t}} \frac{(R_{A,t}+x_{j,t}) + R_t d_t}{2} dx_{j,t} \quad (31)$$

$$+\frac{1}{2h}\int_{\frac{R_t d_t + bk_t^{MIN}}{\lambda} - R_{A,t}}^{h} \frac{(1+\lambda)(R_{A,t}+x_{j,t})}{2} dx_{j,t}$$

Note that the intervals of integration are adjusted to take bk_t^{MIN} into account. Following the same procedure seen earlier it is straightforward to show that the internal optimum is given by

$$bk_t^{ACT} = bk_t + \frac{1}{R_t}\frac{1-\lambda}{2-\lambda} bk_t^{MIN} \quad (32)$$

where bk_t is the economic capital. Note that for intermediate values of λ (close to 0.5) the coefficient of bk_t^{MIN} on the r.h.s. is close to one third; hence $bk_t^{ACT} > bk_t^{MIN}$ unless bk_t^{MIN} is much higher than bk_t In other words, if the capital constraint is not too tight, banks will normally maintain extra capital above the minimum required, a point stressed by Elizaldea and Repullo [49]. This range, where the capital constraint is not binding (though it does affect the bank's capital) is represented by the segment AB in the graph below.

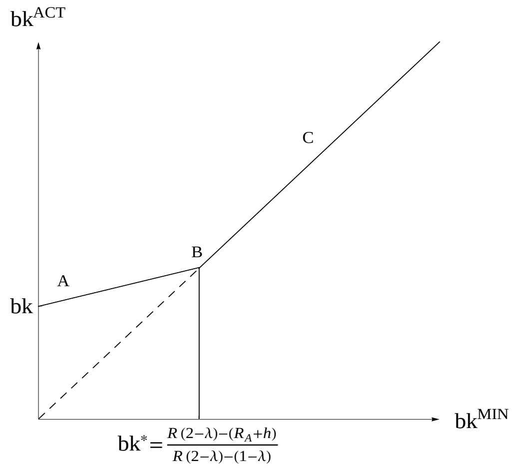
The actual deposit ratio in this case is given by

$$d_t^{ACT} = d_t - \frac{1}{R_t}\frac{1-\lambda}{2-\lambda} bk_t^{MIN} = \frac{1}{R_t}\frac{R_{A,t}+h}{2-\lambda} - \frac{1}{R_t}\frac{1-\lambda}{2-\lambda} bk_t^{MIN}$$

a lower value than in the absence of constraint (i.e. when $bk_t^{MIN} = 0$), as one would expect.

Only when the capital requirement is sufficiently high (segment BC in the graph below) it will be strictly binding, i.e. the actual capital ratio set ex-ante will coincide with the regulatory minimum. The threshold is $bk_t^{MIN} = \frac{1-\frac{1}{R_t}\frac{R_{A,t}+h}{2-\lambda}}{1-\frac{1}{R_t}\frac{1-\lambda}{2-\lambda}} = \frac{R(2-\lambda)-(R_{A,t}+h)}{R(2-\lambda)-(1-\lambda)}$. Above this value

$$bk_t^{ACT} = bk_t^{MIN} \quad (33)$$



In addition to replacing equation 12 with 32 or 33, depending on the regime, we need to modify the accumulation of capital, equation 16. In the non strictly binding regime, solving 31 for the return of the capitalist and substituting in the accumulation equation we get:

$$BK_t = \theta[BK_{t-1} + \frac{(R_{A,t} + h - R_t d_t^{ACT})^2 - (bk_t^{MIN})^2}{8h} Q_t K_t] \tag{34}$$

which, we one can easily see, reduces to the standard accumulation equation 16 for $bk_t^{MIN} = 0$. In the strictly binding regime:

$$BK_t = \theta[BK_{t-1} + \frac{[R_{A,t} + h - R_t(1 - bk_t^{MIN})]^2}{8h} Q_t K_t]$$

Figure 8 and 9 show respectively, under our usual productivity shock, the responses under the first regime (where capital is optimized by the bank and the constraint exists but is not strictly binding) and the second regime (capital constraint strictly binding). In each figure, the capital regulation is calibrated so as to mimic three alternative regimes (see Appendix II for numerical details); in the first the required capital ratio is fixed (as in Basel I[9]); in the second it is moves anticyclically (decreasing when output is above potential, hence producing pro-cyclical macroeconomic effects), as in Basel II[10]; as our third case, we consider the performance of a hypothetical

[9]In fact, it has been noted that capital regulation is slightly procyclical also under Basel I, due to a number of accounting and other factors. We disregard this.

[10]Kashyap and Stein [39] report very different estimates of the degree of procyclicality of Basel II, depending on methodologies, data, etc. What seems to be very robust is the *sign* – Basel II is clearly procyclical in the sense that

regime where the cyclical property of the capital requirement is opposite to that under Basel II, as determined by inverting the sign of the exponent b_1^c; we refer to this regime as "Basel III".

In figure 8 we see that the Basel II regime results in a strong amplification of the short run effect of the shock on all variables in the model. The amplification is particularly evident on output, investment and employment, but also bank leverage and risk react more under this shock in a Basel II environment. Conversely, the Basel III regime implies a more moderate response of the macro and banking variables, relatively to Basel I, as it turns out that the profile of response under Basel I is rather similar to that observed in the absence of capital regulation. Basel III is quite effective in insulating the effects of the shock on the balance sheet and on the riskiness of the banking system.

Comparing figure 9, where the constraint is strictly binding, we see that a rigid constraint results in rather sharp movements in the macro variables, which oscillate before returning to the steady state[11]. The cyclical amplification is much sharper under Basel II, consistently with the results in the previous figure. Note that the presence of capital regulation, though having the possibly undesirable effect of accentuating the business cycle, is actually successful in containing bank risk: specifically, under a fixed capital ratio bank risk oscillates less not only relative to Basel II, but also (though this is not shown in the figure) relative to the case in which there is absence of capital regulation. The stabilizing properties of the "Basel III" case, where banks are required to build up capital buffers when the cyclical position of the economy is strong, and vice versa in case of economic slowdown, are quite evident under al types of shock; not only the one shown here – we omit to report this evidence for brevity. This is true both in the case where banks are strictly constrained by capital regulation, and in the "soft binding" case illustrated earlier in which they maintain a buffer above the regulatory minimum.

8 Optimal Monetary Policy and Bank Capital Regulation

We compare the performance of alternative policy combinations using three criteria: household welfare, output volatility and inflation volatility. Household welfare, calculated from the utility function, is clearly the most consistent criterion if one remains within the model's assumptions.

the capital requirements on a given loan pool increase more, when the economy decelerates, relative to what they did under Basel I.

[11] To facilitate convergence in this strict Basel regime, we had to modify somewhat the steady state values by increasing th steady state capital ratio and lowering the steady state capital accumulation.

Output and inflation volatilities are alternative, ad hoc but frequently used, measured of policy performance.

Some observations on the computation of welfare are in order. First, we cannot safely rely on first order approximations to compare the welfare associated to monetary policy rules, because in an economy with time-varying distortions stochastic volatility affects both first and second moments[12]. Since in a first order approximation of the model solution the expected value of a variable coincides with its non-stochastic steady state, the effects of volatility on the variables' mean values is by construction neglected. Policy alternatives can be correctly ranked only by resorting to a higher order approximation of the policy functions[13]. Additionally one needs to focus on the *conditional* expected discounted utility of the representative agent. This allows to account for the transitional effects from the deterministic to the different stochastic steady states respectively implied by each alternative policy rule.

Our metric for comparing alternative policies is the fraction of household's consumption that would be needed to equate conditional welfare $\mathcal{W}_0$ under a generic policy to the level of welfare $\widetilde{\mathcal{W}}_0$ implied by the optimal rule. Such fraction, Ω, should satisfy the following equation:

$$\mathcal{W}_{0,\Omega} = E_0 \left\{ \sum_{t=0}^{\infty} \beta^t U((1+\Omega)C_t) \right\} = \widetilde{\mathcal{W}}_0$$

Under a given specification of utility one can solve for Ω and obtain:

$$\Omega = \exp\left\{ \left(\widetilde{\mathcal{W}}_0 - \mathcal{W}_0 \right) (1-\beta) \right\} - 1 \tag{35}$$

We compare the performance of alternative monetary policy combinations when the model is hit by three shocks, productivity, government expenditure and monetary policy, calibrated as indicated earlier.

The monetary policy rules we consider belong to the class represented by (28). We limit our attention to simple and realistic monetary policy functions, among those most frequently discussed in the literature. We consider two groups of rules – see table just below. The first group is a

[12] See for instance Kim and Kim [40], Schmitt-Grohe and Uribe [52], [53], [54], Faia and Monacelli [32], Faia [29], Faia [30].

[13] See Kim and Kim [40] for an analysis of the inaccuracy of welfare calculations based on log-linear approximations in dynamic open economies.

standard Taylor rule with an inflation response coefficient of 1.5 and an output response coefficient of 0.5, plus variants with interest rate smoothing (coefficient 0.6) and a reaction alternatively to the asset price or to the (change of) the deposit ratio. The coefficient of the leaning against the wind term is normally 0.5, as in figure 7, except when convergence problems are encountered, in which case the coefficient is reduced to 0.1. Our second group of rules is identical to the first except that it embodies a more aggressive response to inflation, with a coefficient of 2.0. Our choice of policy rules allows to examine deviations from the standard Taylor formulation in three directions: a more aggressive response to inflation, interest rate smoothing and leaning against the wind, in two variants, respectively represented by a response to the asset price or to bank leverage.

Monetary policy rules					
	Coefficients				
Rule	ϕ_π	ϕ_y	ϕ_q	$\phi_{\Delta d}$	ϕ_r
Flexible inflation response	1.5	0.5	0	0	0
... *with reaction to asset price*	1.5	0.5	0.5 or 0.1	0	0
... *with reaction to bank leverage*	1.5	0.5	0	0.5 or 0.1	0
... *with smoothing*	1.5	0.5	0	0	0.6
... *with smoothing and reaction to asset price*	1.5	0.5	0.5 or 0.1	0	0.6
... *with smoothing and reaction to bank leverage*	1.5	0.5	0	0.5 or 0.1	0.6
Aggressive inflation response	2.0	0.5	0	0	0
... *with reaction to asset price*	2.0	0.5	0.5 or 0.1	0	0
... *with reaction to bank leverage*	2.0	0.5	0	0.5 or 0.1	0
... *with smoothing*	2.0	0.5	0	0	0.6
... *with smoothing and reaction to asset price*	2.0	0.5	0.5 or 0.1	0	0.6
... *with smoothing and reaction to bank leverage*	2.0	0.5	0	0.5 or 0.1	0.6

Before turning to policy combinations, in table 3 we show the performance of the monetary policy rules under alternative parameters of the banking model. We consider different combinations of entrepreneurial risk, h, and of the liquidation discount, λ; the first moves between 0.45 (our benchmark) and 0.55, the second between 0.35 and 0.45 (benchmark). Intuitively, high h and a low λ should prevail under stressed market conditions, when uncertainty is high and liquidation values low.

The table shows three metrics: the first is our expected conditional welfare, namely the percentage of consumption costs computed from equation 35 relatively to the optimal rule (the one with higher welfare); the second is the volatility of output of each policy relatively to the one featured by the optimal rule (the one with lower output volatility); the third is the volatility of inflation relatively to the one featured by the optimal rule (the one with lower inflation volatility). By construction, hence the best policy in each column shows an entry equal to zero. To illustrate, the three entries at the top left side of the table say that, under the first set of parameter values, the first rule (standard Taylor) entails a welfare loss relative to the welfare maximizing one (aggressive Taylor with reaction to Q) equivalent to 0.0995 percent of household consumption, or an increase in output volatility relative to the output volatility minimizing one (again aggressive Taylor with reaction to Q) equal to 0.2036 percent of output (see equation 35), or a higher inflation volatility relative to the inflation volatility minimizing one (aggressive Taylor with smoothing and reaction to bank leverage) equal to 0.4105. Evidently, the numbers in the table are comparable only within, not across columns.

The first clear result in table 2 is that all best rules incorporate an aggressive response to inflation. This is true not only when the choice criterion is the volatility of inflation, case in which such outcome would intuitively be expected, but also when the criterion is welfare (defined over consumption and leisure) or output volatility. Moreover, all optimal rules incorporate a leaning against the wind behavior. Which rule wins the contest depends on the criterion used. Based on welfare and output stabilization, the optimum is a Taylor rule with a reaction to the asset price. A rule with smoothing and reaction to bank leverage is appropriate when the criterion chosen is inflation stabilization. Note that in all cases the differences in performance under the welfare criterion are very small: very rarely we see rules that deviate from the best one more than 0.1 percent of consumption. It should be kept in mind that welfare comparisons, including relative ones, are sensitive to the parameters of the utility function, risk aversion in particular, and are also affected by the presence/absence of frictions in consumption. The differences in volatility of output and inflation are, instead, economically significant. The differences in ranking are quite robust to the four different parameter sets.

Table 3 shows the performance of the same rules under four bank capital regimes: free capital (no regulation), Basel I, II and III. This time the entries are calculated relative to the optimal combination of monetary rule and bank capital regime in the whole table, not within each column (comparisons within each column are still possible, however). The first result is that, regardless of the criterion, the best policy combination includes an aggressive monetary policy rule with leaning against the wind and Basel III. Again, under the welfare and output criteria the best rule reacts to Q, while under the inflation criterion it reacts to leverage and includes interest rate smoothing. Note that the results in the table are consistent with the claim of Bernanke and Gertler [7] that reacting to set prices is not effective in stabilizing inflation; leaning against the wind is nonetheless appropriate, if one consider reacting to bank leverage. Again, the differences in welfare are always very small, whereas the differences in terms of inflation and output volatility are economically significant.

Finally, in Table 4 we look at the same rules under three Basel regimes, this time assuming that the minimum capital ratio is strictly binding, so that banks always choose a capital ratio equal to the minimum required. The message is clear: under all metrics, the best monetary policy rule is an aggressive Taylor rule with a reaction to bank leverage. Note that in this case, in which banks are subject to a rigid constraint, the losses of deviating from the optimal monetary policy rule are much higher than in the previous table.

9 Conclusions

Since the crisis started, views on how to conduct economic policies have changed. Though a new consensus has not emerged yet, some old well established paradigms are put into question. One area concerns the interaction between bank regulation and monetary policy. The old consensus, according to which the two policies should be conducted in isolation, each pursuing its own goal using separate sets of instruments, is increasingly challenged. After years of glimpsing at each other from the distance, monetary policy and prudential regulation – though still unmarried – are moving in together. This opens up new research horizons, highly relevant at a time in which central banks on both sides of the Atlantic are acquiring new responsibilities in the area of systemic stability.

In this paper we tried to move a step forward by constructing a new macro-model that integrates banks in a meaningful way and using it to analyze the role of banks in transmitting shocks to the economy, the effect of monetary policy when banks are fragile, and the way monetary policy and bank capital regulation can be conducted as a coherent whole. Our conclusions at this stage are summarized in the introduction, and need not repeating here.

While our model brings into the picture a key source of risk in modern financial system, namely leverage (and implicitly, also the maturity mismatch between bank assets and liabilities), there are also others that we have left out from our highly abstract construct. Of special importance is the interconnection within the banking system. As some have noted (see e.g. Morris [47], Brunnermeier et al. [16]), a system where leveraged financial institutions are exposed against each other and can suddenly liquidate positions under stress is, other things equal, more unstable than one in which banks lend only to entrepreneurs, as in our model. Introducing bank inter-linkages and heterogeneity in macro models, along the direction of Gertler and Kiyotaki [36] is, we believe, one of the first and most important challenges in this line of research[14].

[14] While we were finishing this work we came across a very recent paper by Gertler and Kiyotaki [36] that introduces bank eterogeneity and interbank exposure in the Gertler-Karadi model, assuming banks operate in islands subject to idiosynchratic shocks.

10 Appendix 1: The banker's maximum problem

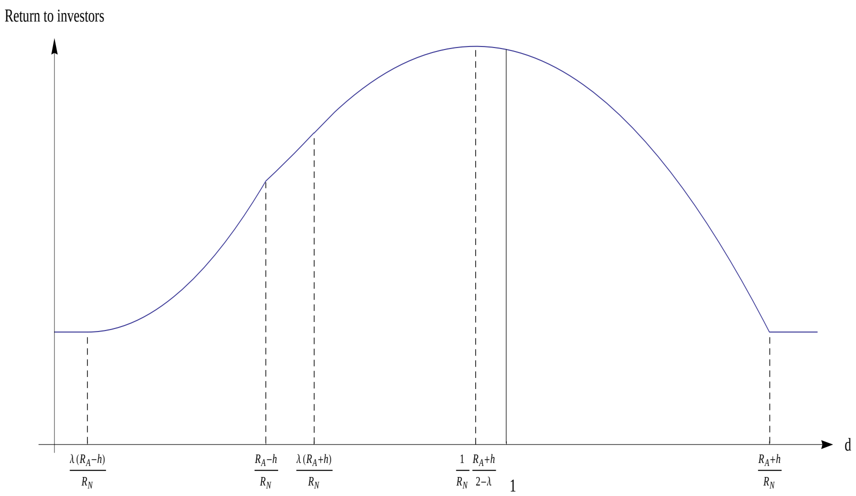
10.1 Uniform density function

Proof of Proposition 1. We want to show that the value of d that maximizes equation 7 (the time subscript is omitted)

$$\frac{1}{2h}\int_{-h}^{Rd-R_A}\frac{(1+\lambda)(R_A+x)}{2}dx+\frac{1}{2h}\int_{Rd-R_A}^{\frac{Rd}{\lambda}-R_A}\frac{(R_A+x)+Rd}{2}dx$$
$$+\frac{1}{2h}\int_{\frac{Rd}{\lambda}-R_A}^{h}\frac{(1+\lambda)(R_A+x)}{2}dx$$

is within the interval $\left(\lambda\frac{R_A+h}{R};\frac{R_A+h}{R}\right)$. To do this we show first that the optimum is not below $\frac{R_A-h}{R}$; than that it is not above $\frac{R_A+h}{R}$; and finally that it cannot be in the interval $\left(\frac{R_A-h}{R};\lambda\frac{R_A+h}{R}\right)$.

1. Consider first very low values of Rd, below $\lambda(R_A-h)$. In this case a run is impossible ex-ante, with or without the bank. The return to outsiders is given by $\frac{1}{2h}\int_{-h}^{h}\frac{(1+\lambda)(R_A+x)}{2}dx=\frac{1}{2}(1+\lambda)R_A$, which does not depend on d. Hence the value of equation 7 in this interval is constant. The graph below shows the shape of the piece-wise function for the following parameter values: $R_A=1.03$; $R=1.01$; $\lambda=0.5$; $h=0.55$.



As Rd grows above $\lambda(R_A - h)$, but below $R_A - h$, the relevant expression becomes

$$\frac{1}{2h}\int_{-h}^{\frac{Rd}{\lambda}-R_A}\frac{(R_A+x)+Rd}{2}dx+\frac{1}{2h}\int_{\frac{Rd}{\lambda}-R_A}^{h}\frac{(1+\lambda)(R_A+x)}{2}dx$$

The derivative with respect to d is

$$\frac{R}{4h}\left[\frac{Rd}{\lambda}-(R_A-h)\right]$$

which is positive and increasing in d_t in the interval we consider. Intuitively, in this region, depending on the realization of $x_{j,t}$, one may fall either in the case where the run is impossible ex-post, or in the case where it is possible without the bank. The return to outside claimants is higher in the second case (because the banker´s fee is smaller), so as d_t increases the overall expected return to outsiders increases. Hence we conclude that the value of $d_t = \frac{R_{A,t}-h}{R_t}$ dominates all values to the left-hand side of it in graph 2.

2. Consider now the opposite case, $R_t d_t > (R_{A,t} + h)$. In this case the expression reduces to a constant, equal to the value already found for the case $R_t d_t < \lambda(R_{A,t} - h)$ (graph 2, right-hand side). In this case the run is certain ex-ante, and depositors get always the same, namely the expected liquidation value of the loan $R_{A,t}$ minus the banker´s fee $\frac{1}{2}(1-\lambda)R_{A,t}$.

3. We are now at the case where $\left(\frac{R_{A,t}-h}{R_t} < d_t < \lambda\frac{R_{A,t}+h}{R_t}\right)$. The derivative of equation 7 with respect to d_t is

$$\frac{2Rd}{8h\lambda}(\lambda-1)^2 > 0$$

This portion of the curve is upward sloping and convex. If the function is continuous at $d = \lambda\frac{R_A+h}{R_t}$[15], we conclude that the value $d = \lambda\frac{R_A+h}{R}$ dominates all points to the left and that the value $d = \lambda\frac{R_A+h}{R}$ dominates all points to the right, QED.

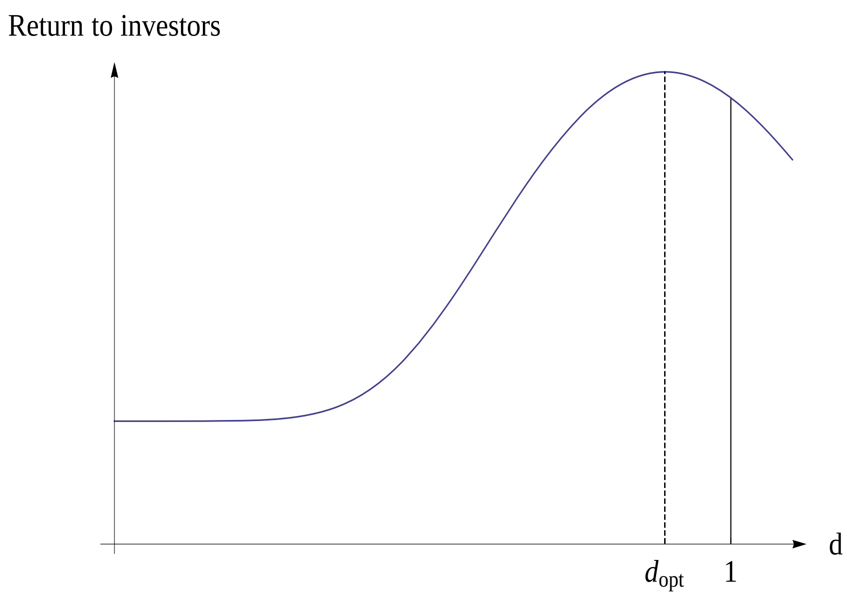
[15] The function is continuous and well behaved for all but very low values of h and λ. More specifically, when $R_A(1-\lambda) - (1+h)\lambda \geq 0$, the function exhibits a discontinuity at $d = \lambda\frac{R_A+h}{R_t}$, which can give rise to a new global maximum at this point for sufficiently low parameter values (e.g. $h = \lambda < 0.35$).

10.2 Normal density function

Let us assume that x follows a zero-mean normal distribution. The expected value of returns to outside investors is

$$
\left(\frac{1}{\sqrt{2\pi\sigma^2}}\right)\left\{\begin{array}{c} \int\limits_{-\infty}^{Rd-R_A} \exp\left[-\frac{x^2}{2\sigma^2}\right]\frac{(1+\lambda)(R_A+x)}{2}dx + \int\limits_{Rd-R_A}^{\frac{Rd}{\lambda}-R_A} \exp\left[-\frac{x^2}{2\sigma^2}\right]\frac{(R_A+x)+Rd}{2}dx+ \\ \int\limits_{\frac{Rd}{\lambda}-R_A}^{\infty} \exp\left[-\frac{x^2}{2\sigma^2}\right]\frac{(1+\lambda)(R_A+x)}{2}dx \end{array}\right\}
$$

Graph 3 shows the expected value of returns to outside investors for d ranging between 0 and 1 under the following parameter set: $R_{A,t} = 1.03$; $R_t = 1.01$; $\lambda = 0.5$, when the distribution of returns follows a standard normal ($\sigma = 0.3$). Sensitivity analysis shows that, as with the uniform distribution, the optimal value of d is positively related to R_A, λ and σ, and negatively related to R.



11 Appendix 2: Calibrating the Basel II regime

In equation 30, the dependence of the minimum capital ratio on the deviation of output from its steady state is intended to mimic the cyclical sensitivity of the risk weights that affect the capital requirements under the Basel II Internal Ratings Based approach. The parameters b_0^c and b_1^c can be calibrated so as to ensure that the resulting required capital ratio is, at each point in the cycle, close to that resulting from the application of the actual Basel II IRB rules.

The IRB risk-weighted approach requires banks to hold capital to cover unexpected losses, for a given confidence level, given the distribution of potential losses. Potential loan losses are determined by the probability of default (PDs) of borrowers, which differ across rating classes, and by their losses conditional on default (losses given default, or LGDs). This methodology, based Merton [46], implies that the capital requirement for a unit of exposure is given by (for details see Basel Committee on Banking Supervision [8])

$$CR = LGD\left\{\Phi\left[\frac{1}{\sqrt{1-\rho}}\Phi^{-1}(PD)+\sqrt{\frac{\rho}{1-\rho}}\right]\Phi^{-1}(.999)-PD\right\}MA$$

where ρ is an estimate of the cross-borrower correlation and MA is an adjustment for average loan maturity. The correlation is approximated by the Basel Committee by means of the following function of PD:

$$\rho = 0.12\left[\frac{1-\exp(-50PD)}{1-\exp(-50)}\right]+0.24\left[1-\frac{1-\exp(-50PD)}{1-\exp(-50)}\right]$$

The maturity adjustment formula is given by

$$MA = \frac{1+(M-2.5)b(PD)}{1-1.5b(PD)}$$

where M is the average maturity of loans, that we assume fixed and equal to 3 years.

We follow Darracq Paries et al. [23] in assuming that LGD is constant over the cycle and equal to 0.45. On the contrary, PDs are typically found to be anticyclical – the stronger the cyclical position, the lower the average PD of non-financial corporations. We modelled the link between the aggregate PD and the cycle, for the euro area, with the regression equation reported in table A1. PD depends on its own lagged value and the (change of) the ratio of output to its trend, modelled with an HP filter (details in the table). The mean lag is about 6 quarters. The impact effect of a one percentage increase in output is to decrease PD by 0.13 percent (the sample average value of PD is .58 percent). The residual of this equation is AR(1) with a persistence parameter of 0.58, and a standard error of the PD shock of 0.1 percent.

The anticyclical relation of PD to output implies a similar response of the capital requirement: when the cyclical position is strong, CR declines because PD declines. This is the "procyclicality" property of Basel II: in a recession, for a given level of capital, the supply of loans has to decline because the regulatory capital ratio increases. To calibrate our parameters we have proceeded as follows: we used the output gap estimates used elsewhere in the paper to calculate the average amplitude and frequency of the cycle, and given these we calculated the average CRs under Basel II and according to equation 30, then we found the values of b_0^c and b_1^c that minimize the distance from the Basel II CRs. Such values are $b_0^c = 1.02$ and $b_1^c = -0.5$. To simulate the impact of the capital ratio under a strictly binding Basel regime, we have scaled down b_1^c to -0.1, to take into account that only a fraction of banks are strictly capital constrained in any given period (between 10 and 30 percent according to sporadic supervisory information). Conversely, a value of $b_1^c = 0$ expresses a capital requirement regime that is insensitive to risk; we have used this assumption to mimic the effect of Basel I, whereas to simulate the Basel III regime we have simply inverted the value of b_1^c.

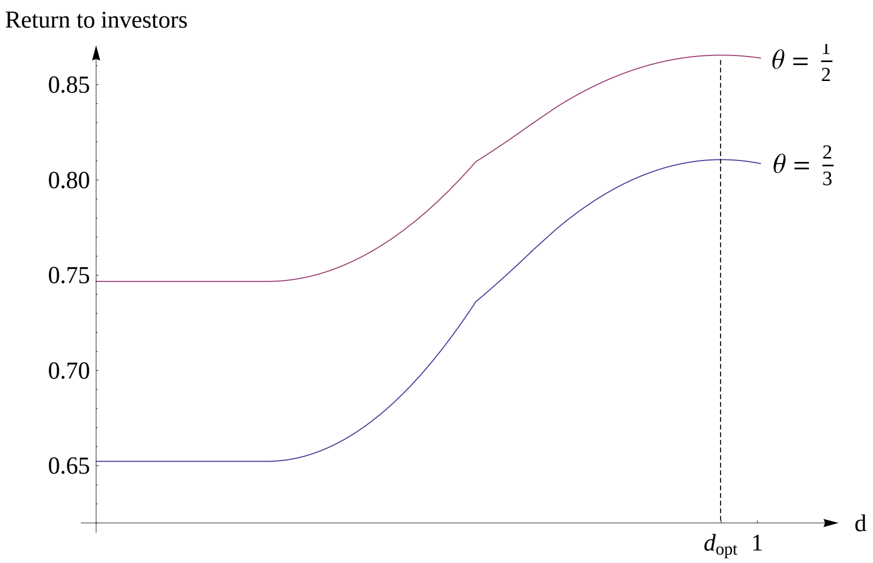
12 Appendix 3: Sensitivity to bargaining power assumption

Alternatively to what assumed earlier, we depart from the assumption that all players have equal bargaining power and show that the solution to the bankers ' problem is unchanged. Let θ be the bargaining power of the banker in his game with the depositor (in case of run) or with the capitalist (in case of no run or possible run). The bargaining power of the depositor (or capitalist) in their respective games is $1 - \theta$.

The payoff function of the depositor and capitalist combined, homologue to 7, is

$$\frac{1}{2h}\int_{-h}^{Rd-R_{A,t}}(R_A+x)[1-\theta(1-\lambda)]dx+\frac{1}{2h}\int_{Rd-R_A}^{\frac{Rd}{\lambda}-R_A}[(R_{A,t}+x)(1-\theta)+\theta Rd]dx+\frac{1}{2h}\int_{\frac{Rd}{\lambda}-R_A}^{h}[1-\theta(1-\lambda)](R_A+x)dx$$

The function is shown in the chart below for two value of θ, $\frac{1}{2}$ and $\frac{2}{3}$. As the graph suggests, the maximum is unchanged.



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Graph A: Bank capital structure and the risk of bank run

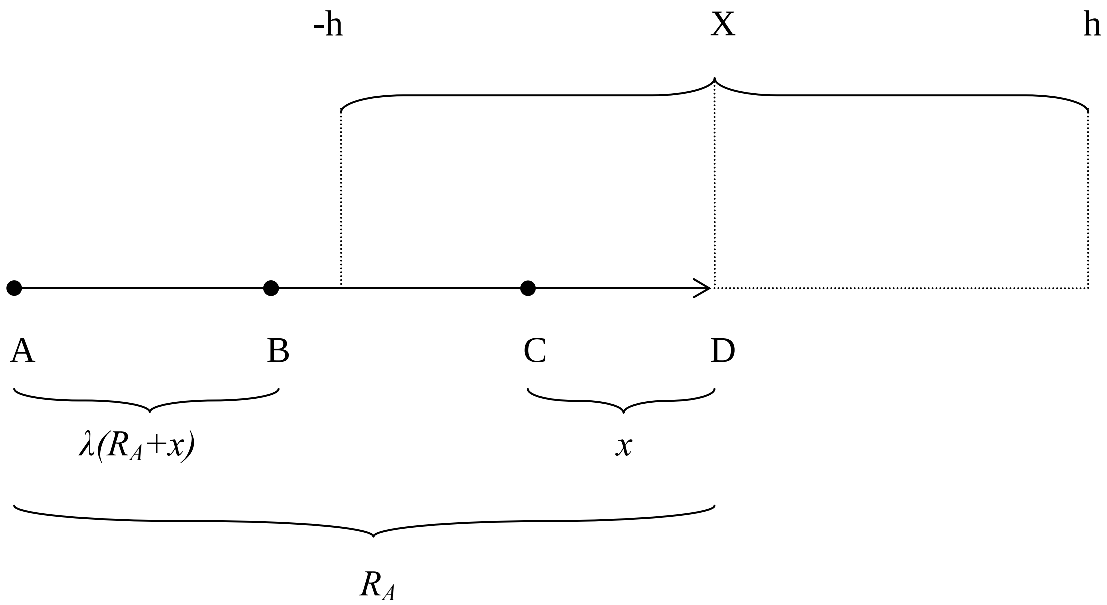

Figure 1: Impulse response to a positive productivity shock

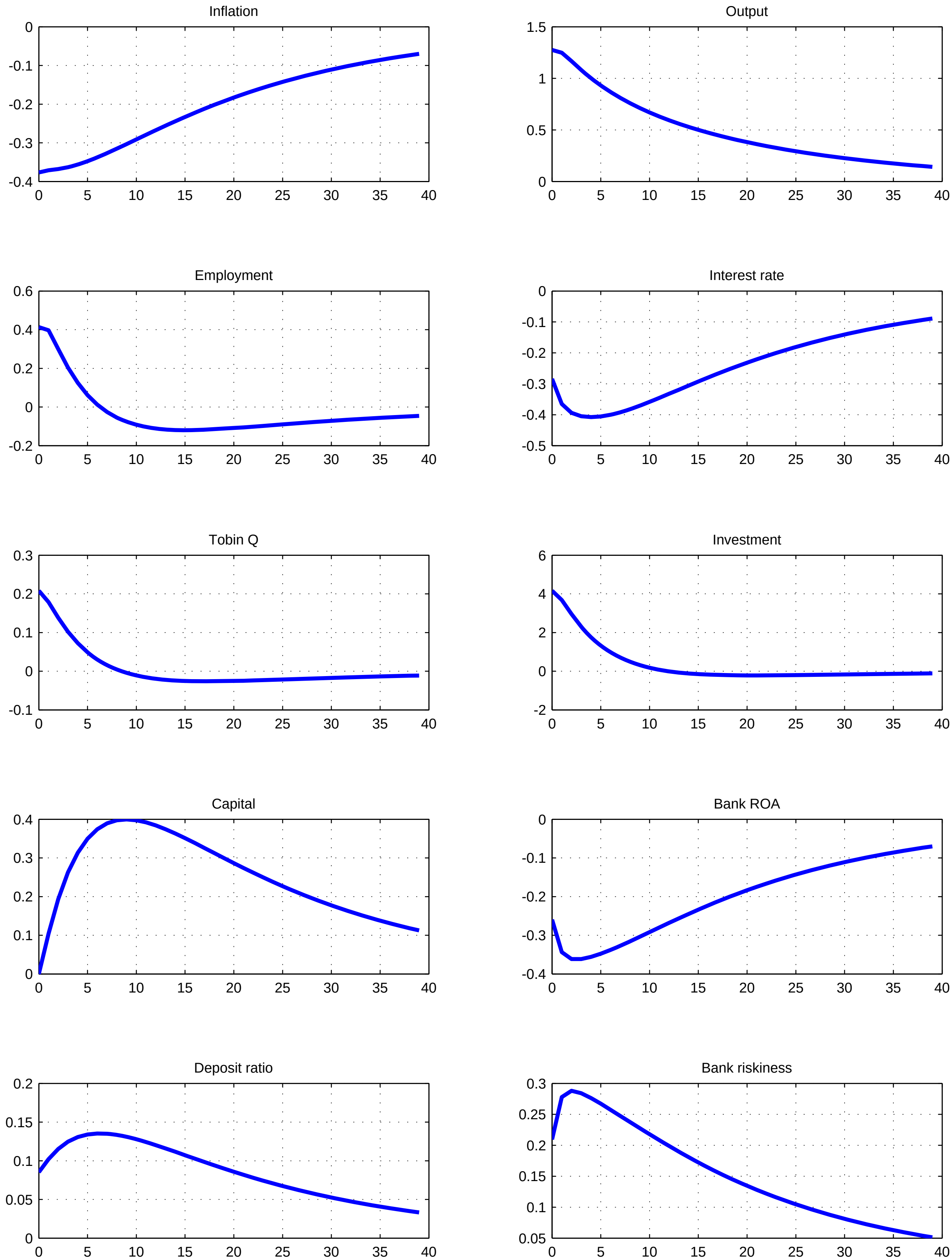

Figure 2: Impulse response to a positive interest rate shock

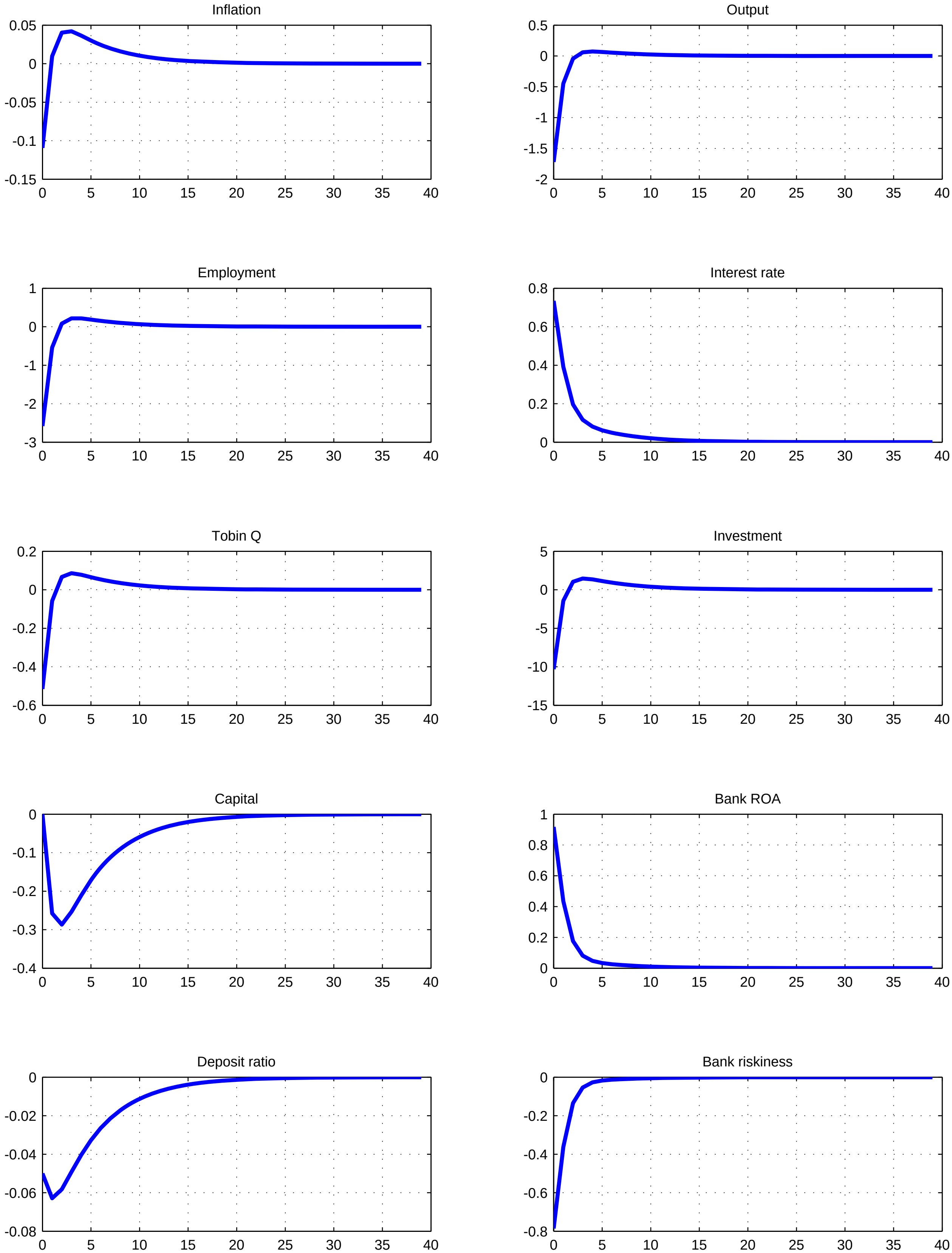

Figure 3: Impulse response to a positive shock in the marginal return on capital

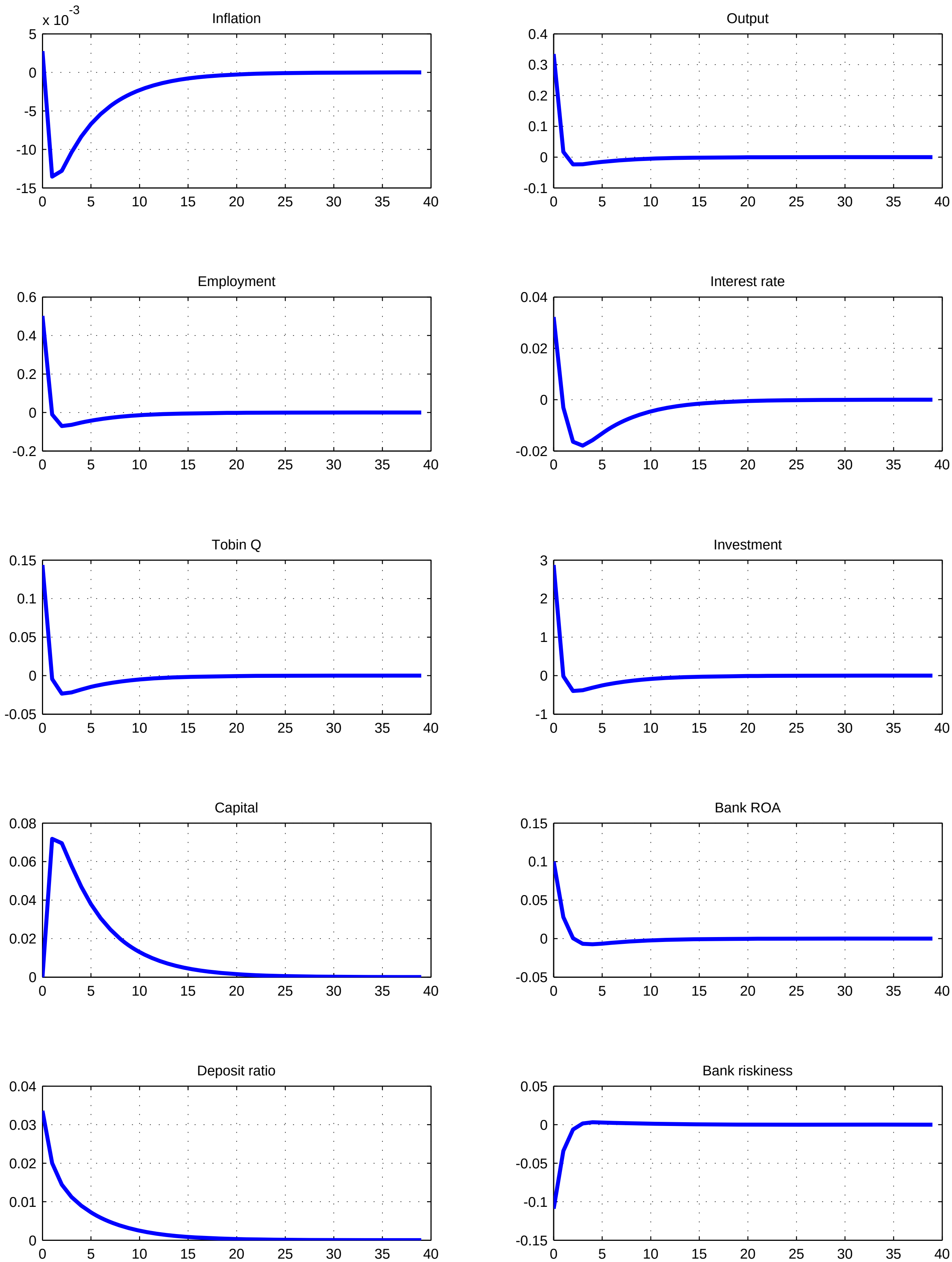

Figure 4: Alternative values of lambda (positive productivity shock)

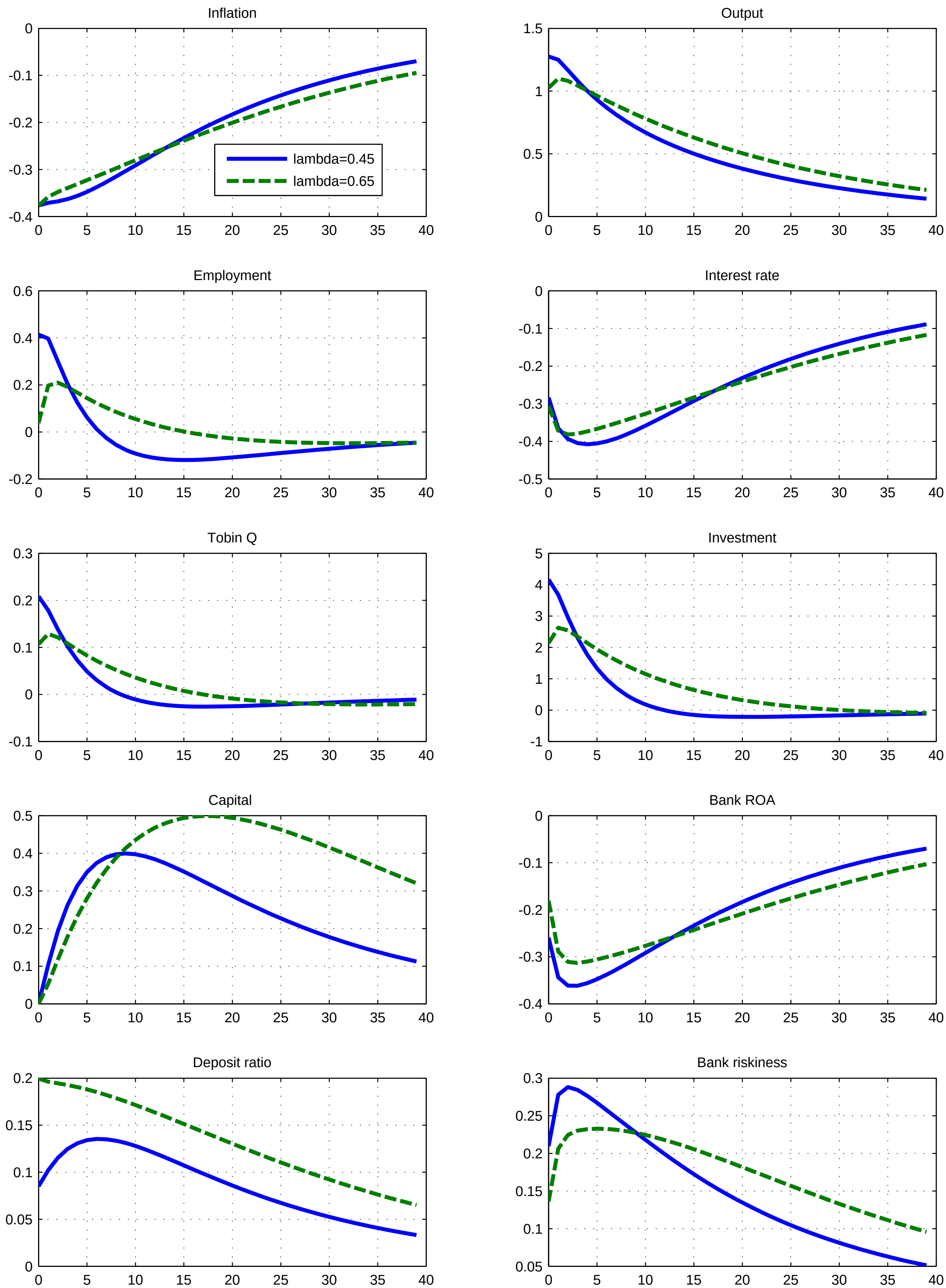

Figure 5: Alternative values of h (positive productivity shock)

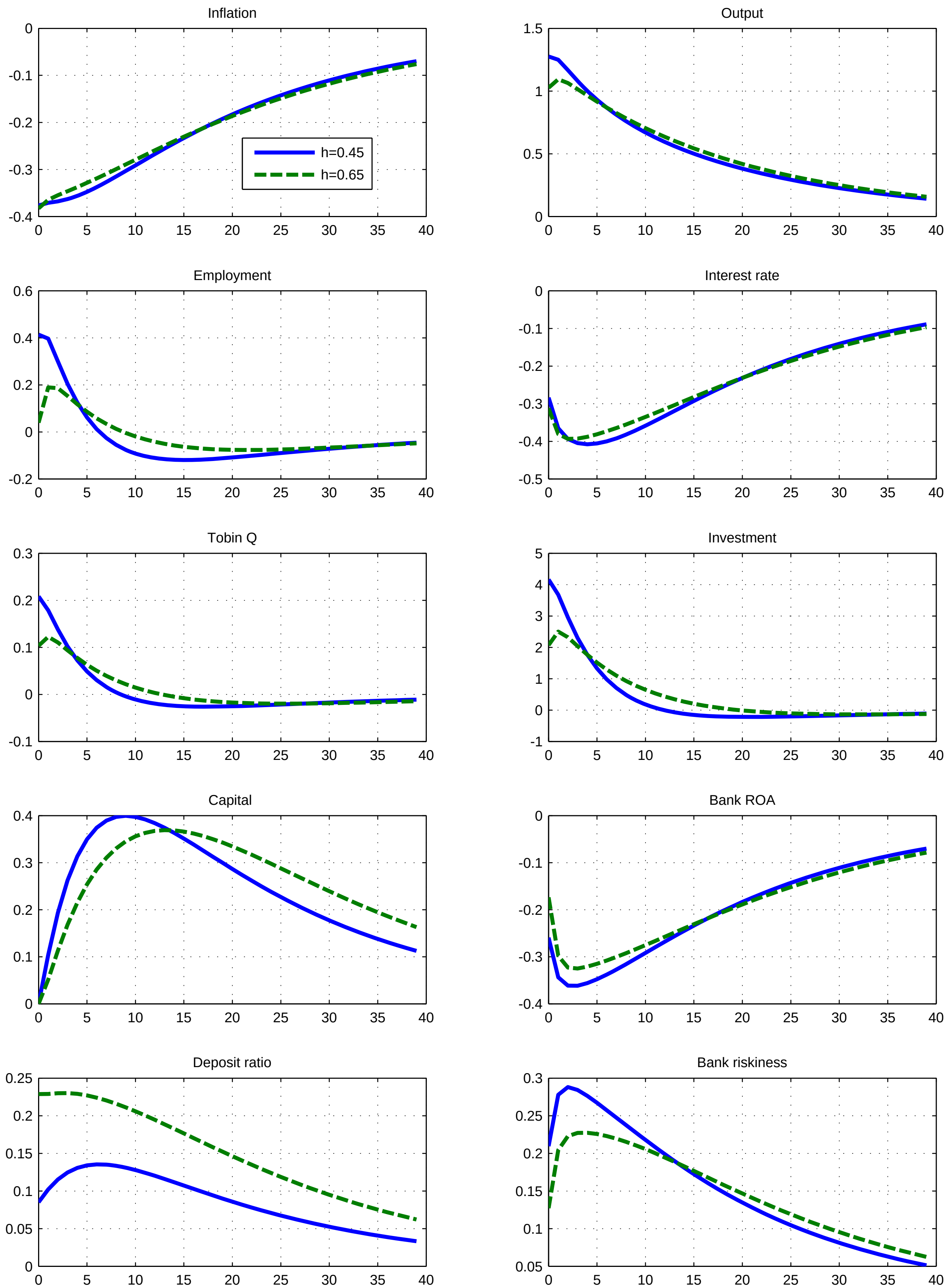

Figure 6: Alternative values of h (positive interest rate shock)

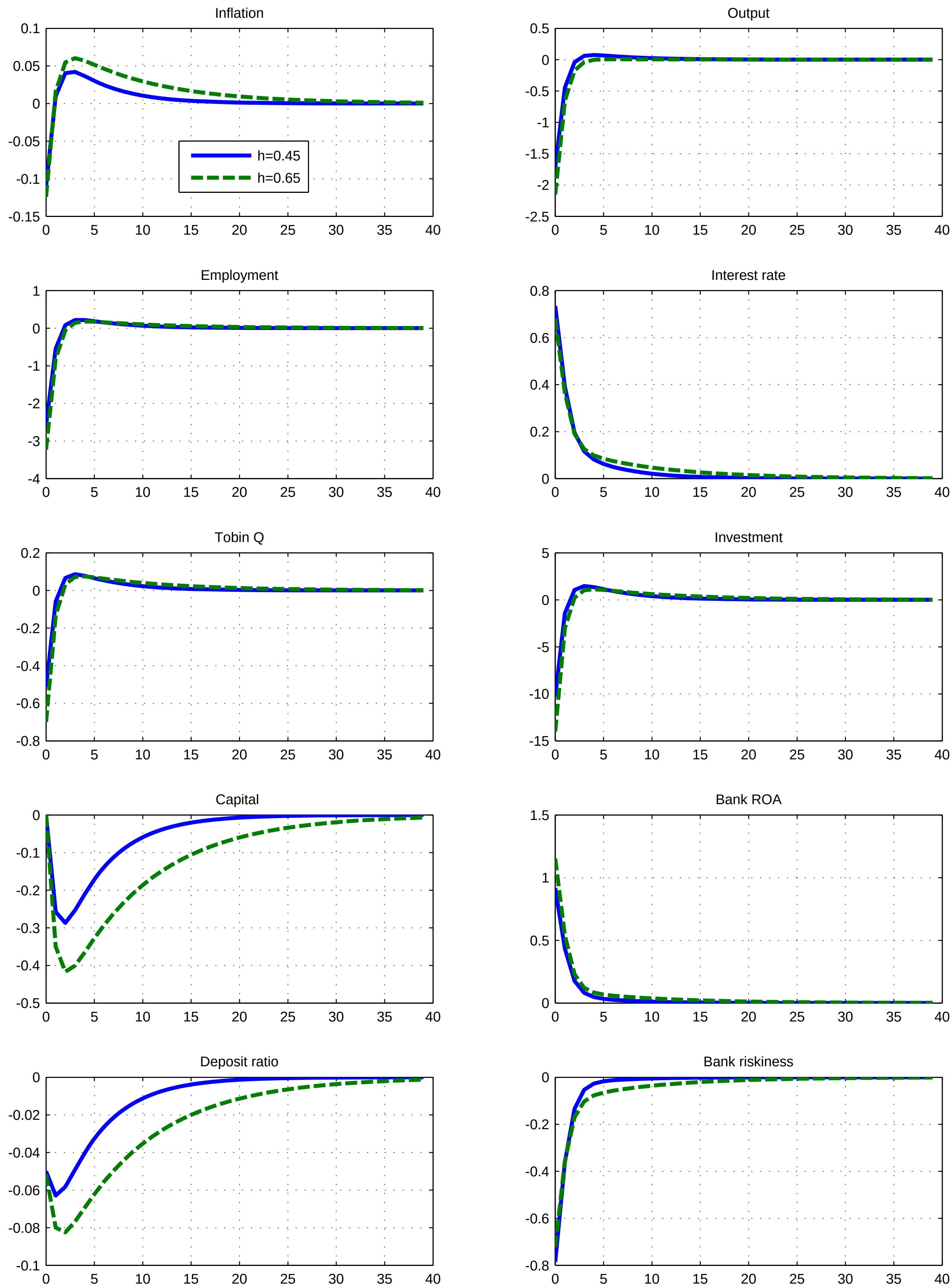

Figure 7: Response to asset prices or leverage (positive shock on marginal return on capital)

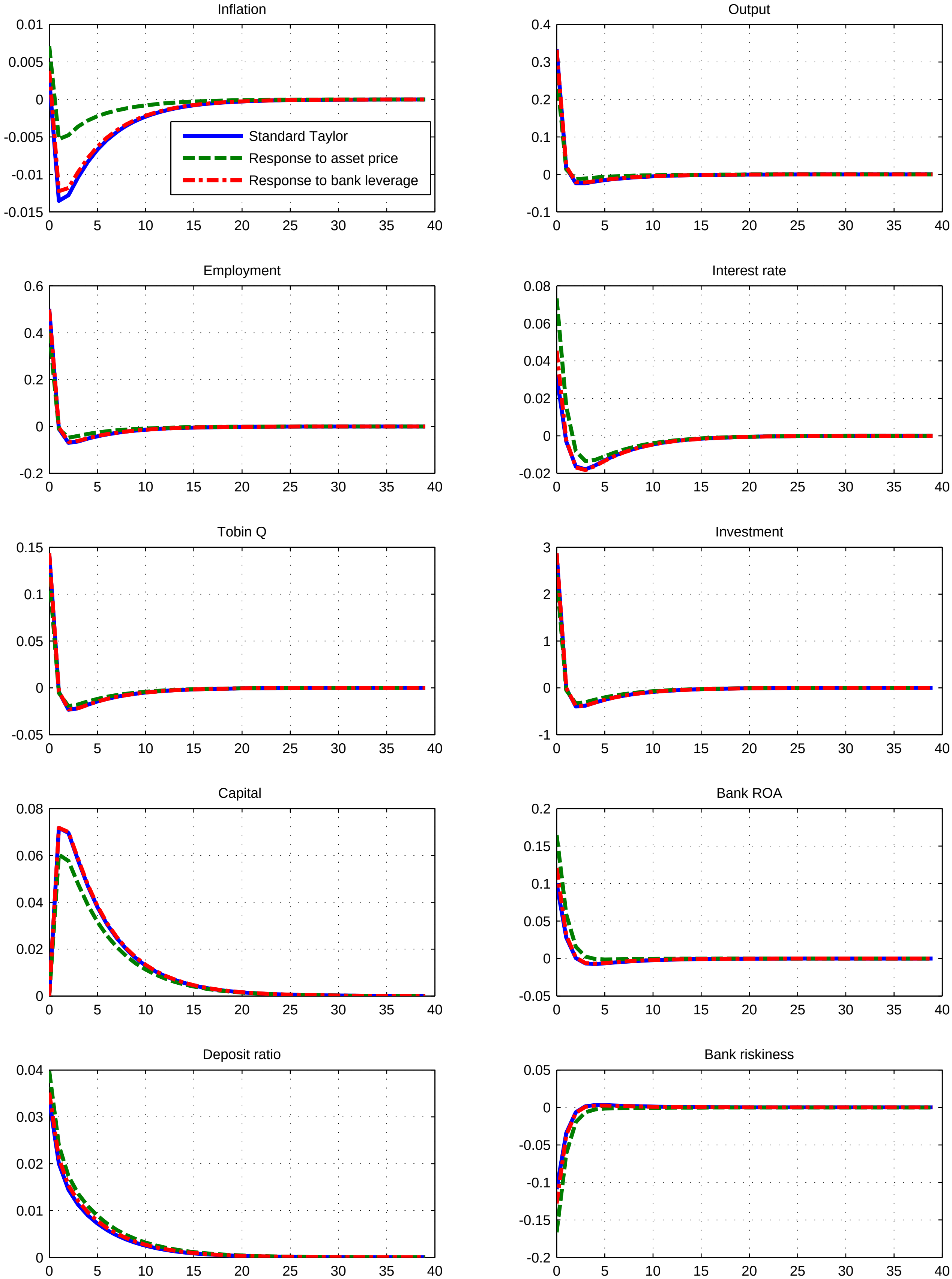

Figure 8: Comparing Basel regimes with soft-binding constraint (positive productivity shocks)

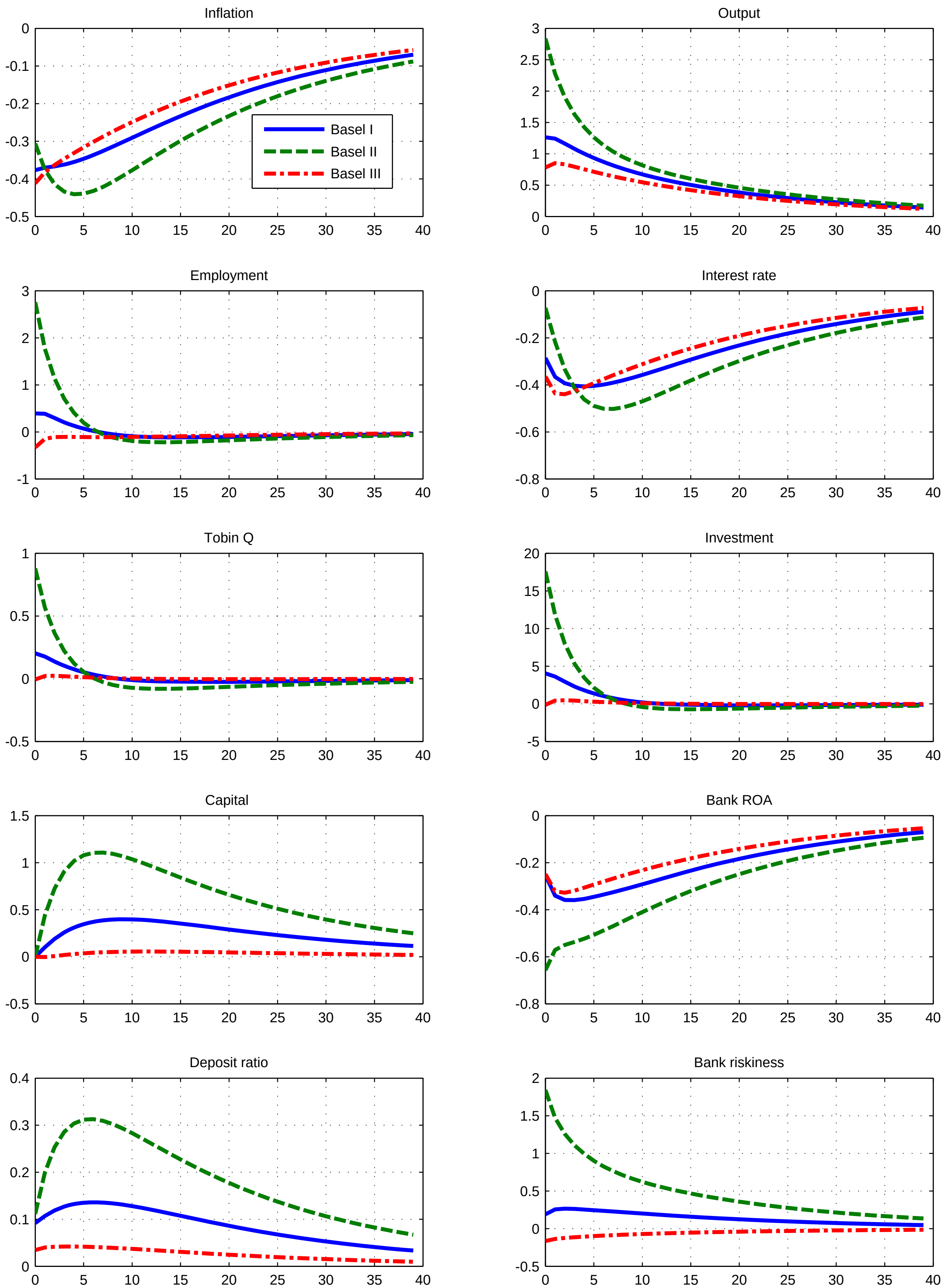

Figure 9: Comparing Basel regimes with hard-binding constraint (positive productivity shocks)

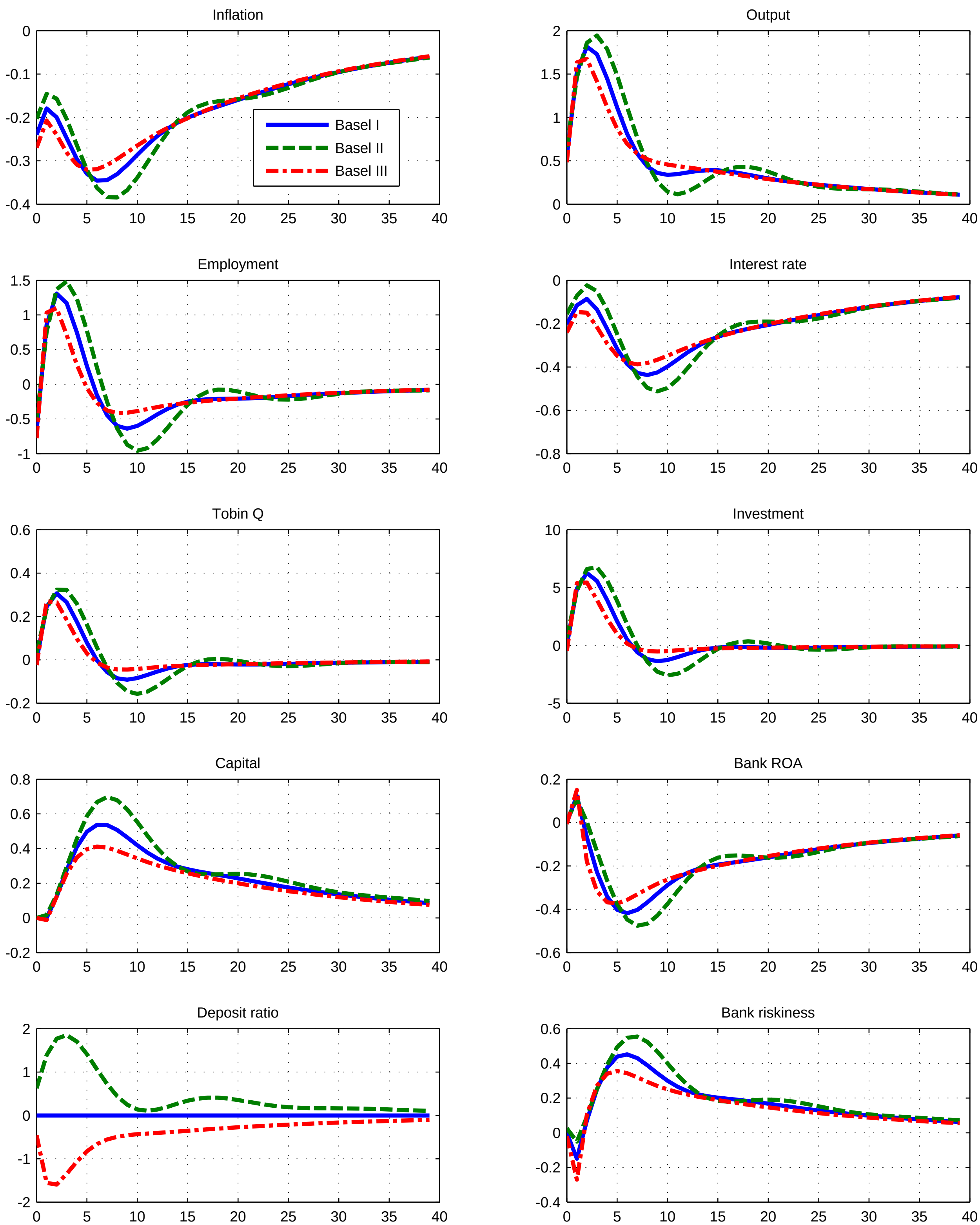

TABLE 2: COMPARING MONETARY POLICY RULES UNDER ALTERNATIVE BANKING PARAMETERS

Policy rules:		h=0.45; λ=0.45			h=0.45; λ=0.35			h=0.55; λ=0.45			h=0.55; λ=0.35		
		Welfare	Output	Inflation	Welfare	Output	Inflation	Welfare	Output	Inflation	Welfare	Output	Inflation
Taylor	Standard	0.0995	0.2036	0.4105	0.1007	0.2373	0.4209	0.0981	0.1665	0.3974	0.0989	0.1786	0.4055
	React to Q	0.0943	0.1639	0.3962	0.0950	0.1942	0.4037	0.0936	0.1334	0.3873	0.0940	0.1431	0.3923
	React to D	0.0986	0.1977	0.4078	0.0999	0.2318	0.4191	0.0970	0.1605	0.3940	0.0980	0.1726	0.4025
	Smoothing	0.0827	0.6000	0.3186	0.0795	0.4926	0.3247	0.0868	0.7437	0.3118	0.0827	0.5884	0.3147
	Sm. and react to Q	0.1747	0.4119	0.6740	0.1702	0.3716	0.6793	0.1807	0.4756	0.6701	0.1752	0.3910	0.6614
	Sm. and react to D	0.0819	0.5890	0.3170	0.0789	0.4834	0.3241	0.0858	0.7301	0.3092	0.0818	0.5765	0.3129
Aggressive Taylor	Standard	0.0006	0.0146	0.0061	0.0007	0.0149	0.0083	0.0006	0.0140	0.0030	0.0006	0.0138	0.0068
	React to Q	**0**	**0**	0.0043	**0**	**0**	0.0057	**0**	**0**	0.0020	**0**	**0**	0.0050
	React to D	0.0004	0.0113	0.0050	0.0005	0.0117	0.0074	0.0003	0.0104	0.0016	0.0003	0.0103	0.0056
	Smoothing	0.0142	0.4556	0.0008	0.0114	0.3486	0.0004	0.0175	0.5883	0.0012	0.0142	0.4563	0.0008
	Sm. and react to Q	0.0469	0.2916	0.1905	0.0452	0.2366	0.1919	0.0467	0.3607	0.1885	0.0467	0.2877	0.1882
	Sm. and react to D	0.0138	0.4459	**0**	0.0110	0.3402	**0**	0.0169	0.5766	**0**	0.0130	0.4458	**0**

The table compares the performance of monetary policy rules under alternative values of the banking parameters. The entries labelled "welfare" show the welfare loss, expressed in percent of steady state consumption, of departing from the optimal combination (that whose entry is zero). For these entries, due to convergence problems in the second-order approximation of the policy function the non-benchmark values of h and λ are set at 0.50 and 0.40, respectively. The entries labelled "output" (or "inflation") show the difference in the conditional volatility of output (or inflation) relative to the optimal combination (that whose entry is zero).

TABLE 3: COMPARING MONETARY POLICY RULES UNDER ALTERNATIVE BASEL REGIMES

Policy rules:		Free capital			Basel I			Basel II			Basel III		
		Welfare	Output	Inflation	Welfare	Output	Inflation	Welfare	Output	Inflation	Welfare	Output	Inflation
Taylor	Standard	0.1006	0.4159	0.4243	0.1007	0.4159	0.4236	0.1046	0.7720	0.4823	0.0970	0.1617	0.3840
	React to Q	0.0954	0.2465	0.3649	0.0956	0.2471	0.3653	0.0985	0.4674	0.3811	0.0927	0.0680	0.3521
	React to D	0.0997	0.3870	0.4113	0.0997	0.3876	0.4106	0.1036	0.7160	0.4106	0.0962	0.1483	0.3759
	Smoothing	0.0839	0.8123	0.3324	0.085	0.8302	0.3323	0.089	1.1364	0.3795	0.0809	0.5624	0.2963
	Sm. and react to Q	0.1758	0.4400	0.6427	0.1774	0.4470	0.6440	0.1806	0.6501	0.6440	0.1739	0.2696	0.6022
	Sm. and react to D	0.0831	0.7575	0.3249	0.0842	0.7761	0.3245	0.088	1.0620	0.3667	0.0802	0.5211	0.2920
Aggressive Taylor	Standard	0.0017	0.2270	0.0199	0.0019	0.2286	0.0198	0.0033	0.4887	0.0344	0.0005	0.0290	0.0109
	React to Q	0.0011	0.1606	0.0122	0.0013	0.1620	0.0124	0.0025	0.3579	0.0166	**0**	**0**	0.0089
	React to D	0.0015	0.2106	0.0143	0.0016	0.2123	0.0141	0.003	0.4577	0.0264	0.0002	0.0219	0.0065
	Smoothing	0.0153	0.6679	0.0146	0.0162	0.6836	0.0148	0.0185	0.9593	0.0318	0.0137	0.4421	0.0025
	Sm. and react to Q	0.048	0.3815	0.1993	0.0486	0.3879	0.1998	0.0511	0.5842	0.2256	0.0460	0.2167	0.1776
	Sm. and react to D	0.0149	0.6198	0.0110	0.0157	0.6360	0.0110	0.018	0.8957	0.0261	0.0133	0.4048	**0**

The table compares the performance of monetary policy rules under alternative bank capital regimes. To avoid convergeence problems, the cyclical response of capital requirements in the three regimes is 0, -0.2 and 0.2 respectively, and in the welfare comparison (where the problem of second-order approximation to the policy function is particularly severe) these values are 0, -0.05 andd 0.05 respectively. The entries labelled "welfare" show the welfare loss, expressed in percent of steady state consumption, of departing from the optimal combination (that whose entry is zero). The entries labelled "output" (or "inflation") show the difference in the volatility of output (or inflation) relative to the optimal combination (that whose entry is zero).

TABLE 4: COMPARING MONETARY POLICY RULES UNDER ALTERNATIVE BASEL REGIMES
(with strictly binding capital requirement)

Policy rules:		Basel I			Basel II			Basel III		
		Welfare	Output	Inflation	Welfare	Output	Inflation	Welfare	Output	Inflation
Taylor	Standard	0.0614	0.8014	0.5574	0.0675	1.2661	0.6077	0.0583	0.5296	0.5428
	React to Q	0.0594	0.7911	0.5453	0.0648	1.2456	0.5857	0.0569	0.5244	0.5361
	React to D	0.0614	0.8014	0.5574	0.1338	2.3993	1.1206	0.0192	0.0880	0.1010
	Smoothing	0.0686	1.0557	0.5508	0.0844	2.1732	0.6724	0.0619	0.7068	0.5252
	Sm. and react to Q	0.1400	1.5889	0.8308	0.1729	3.6066	0.9662	0.1265	1.0711	0.8008
	Sm. and react to D	0.0686	1.0557	0.5508	0.1579	4.6099	1.1756	0.0285	0.3266	0.1853
Aggressive Taylor	Standard	0.0106	0.3802	0.2145	0.0122	0.7123	0.2321	0.0103	0.1943	0.2188
	React to Q	0.0105	0.3776	0.2124	0.0119	0.7046	0.2263	0.0102	0.1932	0.2182
	React to D	0.0106	0.3802	0.2145	0.0305	1.1474	0.4912	**0**	**0**	**0**
	Smoothing	0.0198	0.5667	0.2498	0.0239	1.0896	0.2963	0.0184	0.3549	0.2449
	Sm. and react to Q	0.0429	0.7978	0.3985	0.0521	1.6667	0.4555	0.0391	0.5087	0.3880
	Sm. and react to D	0.0198	0.5667	0.2498	0.0456	2.0547	0.5564	0.0088	0.1788	0.0838

The table compares the performance of monetary policy rules under alternative bank capital regimes. The cyclical response of capital requirements in the three regimes is 0, -0.1 and 0.1 respectively. The entries labelled "welfare" show the welfare loss, expressed in percent of steady state consumption, of departing from the optimal combination (that whose entry is zero). For these entries, due to convergence problems the cyclical response of capital requirements in the three regimes is set at 0, -0.05 and 0.05 respectively The entries labelled "output" (or "inflation") show the difference in the volatility of output (or inflation) relative to the optimal combination (that whose entry is zero).

Table A1: Link between GDP and corporate probabilities of defaults in the euro area

Dependent Variable: PD
Method: Least Squares
Date: 06/15/10 Time: 20:10
Sample (adjusted): 1995Q3 2009Q4
Included observations: 58 after adjustments
Convergence achieved after 6 iterations
Newey-West HAC Standard Errors & Covariance (lag truncation=3)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.097466	0.060223	1.618405	0.1114
PD(-1)	0.829403	0.130329	6.363929	0.0000
D(PERC_DEV_GDP_FROM_HP)	-0.125905	0.043360	-2.903730	0.0053
AR(1)	0.568747	0.171038	3.325274	0.0016

R-squared	0.944649	Mean dependent var	0.579167
Adjusted R-squared	0.941574	S.D. dependent var	0.448131
S.E. of regression	0.108320	Akaike info criterion	-1.540980
Sum squared resid	0.633595	Schwarz criterion	-1.398881
Log likelihood	48.68842	F-statistic	307.1967
Durbin-Watson stat	1.838241	Prob(F-statistic)	0.000000
Inverted AR Roots	.57		

Equation: $PD_t = \text{constant} + \alpha PD_{t-1} - \beta\Delta(y-y^{SS}) + \text{error AR(1)}$

Notes:

- Quarterly euro area data.
- **PD**: Quarterly averages of the median probability to default if euro area non financial firms. Source: Moody's KMV.
- **$(y-y^{SS})$**: Euro Area (12) real GDP, seasonally adjusted; deviations from HP filter ($\lambda = 1600$). Source: ESA.
- Newey-West HAC standard errors (lag truncation=3).