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The lending channel under optimal choice of monetary policy

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The views expressed are those of the authors and do not necessarily reflect the views of the Bank of Finland.

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The lending channel under optimal choice of monetary policy

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Abstract

Building on Cecchetti and Li (2005), we show that the bank lending channel affects monetary policy trade-offs only when interest rates affect marginal costs of production (ie when there is a cost channel of monetary policy) in the New Keynesian monetary policy model. In our calibrated model the resulting impact of the bank lending channel on output-inflation trade-offs is quantitatively small and of ambiguous sign. When bank capital varies counter cyclically and bank loan rates have a relatively large impact on marginal costs, variation of bank loan margins improves monetary policy trade-offs. The new Basel accord, by increasing capital requirements during economic downturns, offsets this beneficial impact.

Keywords: bank capital, bank lending, capital buffers, pro-cyclicality, capital regulation, cost channel, credit channel, loan margins, monetary trade-offs

JEL classification numbers: E51, E52, G21

Pankkien luottokanava ja optimaalinen rahapolitiikka

Suomen Pankin keskustelualoitteita 33/2007

Juha Kilponen – Alistair Milne
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Tässä keskustelualoitteessa arvioidaan pankkien luottokanavan vaikutusta optimaaliseen rahapolitiikkaan uuskeynesiläisessä rahapolitiikkamallissa. Tavanomaista uuskeynesiläistä rahapolitiikkamallia on laajennettu lisäämällä siihen pankkien luottokanavan lisäksi rahapolitiikan kustannuskanava. Mallissa pankit ylläpitävät minimipääomavaatimusta suurempia pääomapuskureita. Pääomapuskurien suuruus vaikuttaa pankkien luotonantoon ja lainakorkoihin, mikä puolestaan välittyy tuotantoon ja inflaatioon rahapolitiikan kustannuskanavan sekä perinteisen korkojen kysyntävaikutuksen kautta. Rahapolitiikan kustannuskanava eli se, että korkojen vaihtelu välittyy suoraan tuotannon rajakustannuksiin, muuttaa yhdessä luotonantokanavan kanssa rahapolitiikan välittymistä inflaatioon ja tuotantoon. Kalibroidussa mallissa luottokanavan vaikutus optimaaliseen rahapolitiikkaan on kuitenkin varsin pieni ja merkiltään epäselvä. Kuitenkin, jos pankkien ylläpitämät pääomapuskurit vaihtelevat vastasyklisesti ja pankkien lainakoroilla on suhteellisen suuri vaikutus tuotannon rajakustannuksiin, on luottokanavan vaikutus optimaalisen rahapolitiikan kannalta myönteinen. Jos pääomapuskurit vaihtelevat myötäsyklisesti, kuten on mahdollista uuden Basel-sopimuksen myötä, luottokanava lisää inflaation ja tuotannon vaihteluita, jolloin talouden stabilointi edellyttää suurempia koron muutoksia.

Avainsanat: pankkien pääoma, luotonanto, pääomapuskurit, myötäsyklisyys, vakavaraisuussääntely, kustannuskanava, luottokanava, luottomarginaalit

JEL-luokittelu: E51, E52, G21

Contents

1 Introduction

A large literature considers the lending channel of monetary transmission. Some analyses suggest that bank balance sheets effects, for example the interaction of bank liquidity or net worth with loan interest rate elasticities, magnify the impact of monetary policy.[1] A related concern is that banking sector weakness may contribute to economic downturns. Such bank crises have been typically been followed – both in emerging and developed economies – by major falls in bank lending and output, suggesting that a deterioration of banking sector net worth can result in substantial output losses.[2] The main trigger of the financial markets turmoil in the second half of 2007 has been the concern that the write down of holdings of sub-prime mortgage securities and the necessity of re-financing other off-balance sheet exposures will erode bank capital and lead to a substantial contraction of bank credit. Bank defaults also help explain the length and severity of the great depression in the US.[3]

Bank capital regulations are also suspected of having undesirable macroeconomic impacts. A tightening of bank capital standards has been often cited as a contributing cause to the US recession of 1990–1991.[4] More recently many commentators have been concerned that the new Basel II accord on bank capital regulation (as agreed by the Basel Committee, 2004) will exacerbate business cycle fluctuations.[5] Under the advanced IRB calculations of the new accord, regulatory capital requirements are increased in cyclical downturns and it is feared that these increases may constrain bank lending and exaggerate cyclical fluctuations of output.

The present paper explores these issues using a macroeconomic model in which monetary policy makers seek to minimise an objective function quadratic in the deviations of both inflation and output around specified targets. A setting of this kind is necessary in order to provide a full discussion of the macroeconomic impact of the bank lending channel, allowing for any offsetting responses in monetary policy. We examine the resulting behaviour of output and inflation under different assumptions about the operation of the bank lending channel and the regulation of bank capital and also use the quadratic objective function to compare intertemporal losses in these different cases.

Our setup has two distinctive features. The first is that we allow banks to hold buffers of capital over and above minimum regulatory capital requirements and for the magnitude of this capital buffer to affect the supply of bank

[1] For example the interaction of liquidity and the response of bank lending to monetary policy, reported by Kashyap and Stein (2000). Our analysis is based a slightly different interpretation of the role of bank balance sheets in monetary transmission.

[2] Hoggarth, Reis and Saporta (2002) find that output losses during crisis periods in developed countries are as much as 10–15% of annual GDP higher on average than in neighbouring countries that did not at the time experience severe banking problems.

[3] As argued by Bernanke (1983). Calomiris and Mason (2003) confirm the importance of US banking failures in the propogation of the great depression using using disaggretated data.

[4] The Sharpe (1995) review of the evidence provided from the many research studies on the US credit crunch of 1990–1991, suggests this was not in fact a major contributing factor outside of New England.

[5] The evidence on procyclicality of the Pillar 1 capital requirements of Basel II is reviewed by Kashyap and Stein (2004) and by Gordy and Howells (2006).

lending. Most previous analysis of the macroeconomic impact of bank capital makes the mechanical and counterfactual assumption that regulatory capital requirements directly constrain the volume of bank lending (ie that bank lending is some multiple of regulatory capital).[6] In practice, as several recent studies have pointed out, banks almost always operate with buffers of capital well in excess of minimum regulatory requirements.[7] In our model a shortfall of this capital buffer – relative to a desired or target level – reduces bank loan supply and increases bank loan margins.

The second distinctive feature is that we allow for the possibility of a 'cost channel' of monetary policy, with either or both market and bank interest rates directly affecting marginal costs of production. In the presence of a cost channel a tightening of monetary policy has the effect not just of reducing output and hence lowering future inflation; it also leads to a rise in current inflation. The cost-channel thus constrains the ability of policy makers to respond to shocks. As we will show the presence of a cost-channel is an important determinant of the macroeconomic impact of bank capital. Without a cost channel, monetary policy can be re-adjusted to offset the impact of changes of bank capital or bank capital regulation on output and inflation.

Our model is in other respects a standard 'New Keynesian' monetary policy model. The dynamics of the output gap and of inflation both depend upon expectations of future output and inflation as well as lagged output and inflation. Monetary policy is chosen so as to achieve the minimisation of a quadratic loss function in output and inflation variability. While this is a standard set up there are some inherent limitations. In order to obtain tractable solutions for optimal policy, this type of model considers only the linearised dynamics for small deviations of state variables – in our case output, inflation, and bank buffer capital – around their long term equilibrium values. The theory of precautionary bank capital suggests that there should be instead a non-linear relationship between bank net worth and bank lending, with relatively small macroeconomic impacts of bank net worth when bank capital is close to desired levels and much larger impacts when there is a substantial shortfall of bank capital. Our simulation results must therefore be interpreted with some care. We believe they capture the operation of monetary policy during normal business cycle fluctuations but not during an extreme systemic event.

The analysis is developed as follows. Section 2 presents a brief overview of the relationship between bank balance sheets and the macro-economy, bringing together some of the different perspectives found in the macroeconomics and finance literatures, and motivating our specification of the lending and cost channels. Section 3 presents our macroeconomic model and discusses its parameterisation. Sections 4 presents our results, using impulse response functions to explore the behaviour of interest rates, output, and inflation under different model specifications and comparing intertemporal losses arising from the variance of output and inflation. Sections 5 concludes with a summary of

[6] For example Blum and Hellwig (1995) or Cecchetti and Li (2005).

[7] See for example Puera and Keppo (2006) and Jokipii and Milne (2006) and other references cited in Section 2 of this paper.

results and a discussion of how the conclusions might alter outside the assumed linear-quadratic modelling framework.

2 Bank loan supply and the cost channel

Most quantitative macro-monetary modelling ignores financial intermediaries, focusing on the relationship between market interest rates and macroeconomic aggregates. Typically households and corporations are assumed to be able to borrow or lend freely at prevailing market rates of interest. While the 'financial accelerator' has been introduced into structural 'New-Keynesian' macromodels (beginning with Bernanke, Gertler and Gilchrist, 1999) and shown to both amplify and propagate business cycle fluctuations, banks and other financial intermediaries have mostly continued to be regarded as passive conduits of monetary policy. To our knowledge the only previous quantitative macro-monetary model with optimal monetary policy and an explicit role for bank balance sheets is Cecchetti and Li (2005). They point out that it is essential to model monetary policy, as well as bank capital and lending decisions, in order to properly understand the macroeconomic impact of bank capital regulation on business cycle fluctuations. They argue that capital requirements need not worsen monetary policy trade-offs, showing, in a standard reduced form monetary policy model where policy makers are concerned to reduce both fluctuations of output and of inflation, that it is possible for policy makers to entirely offset the impacts of bank capital requirements on aggregate demand, adjusting the monetary policy rule so as to re-establish the policy maker's preferred trade-off between output and inflation. As we will show the same argument applies more broadly. It may also be possible for policy makers to adjust interest rates so as to entirely offset the impact of bank balance sheets and bank interest rates on output and inflation and hence that the bank lending channel may have no impact on output-inflation tradeoffs.

The present paper builds on Cecchetti and Li (2005), with the crucial difference that we take account not just of the lending channel but also of the cost-channel impact of monetary policy. This means that it is no longer possible for policy makers to entirely offset the impact of the bank lending channel on output and inflation. We also improve on their analysis by introducing a more realistic treatment of bank capital management and bank loan supply, modelling the impact of bank capital on bank loan supply through departures of the capital buffer from its target level. The remainder of this section grounds our treatment of bank loan supply and the cost channel in the broader literature.

Several theoretical analyses stresses the role of banks in overcoming information asymmetries, for example through the monitoring of bank borrowers that may otherwise declare default and avoid repayment of loans. As discussed by Holmstrom and Tirole (1997), such monitoring implies *two* additional channels of macroeconomic propagation, not captured in standard models of the macroeconomy. First (as previously analysed by for example

Bernanke and Gertler, 1989) there is what is usually referred to as the 'financial accelerator' or 'balance sheet' channel of business cycle propagation. The ability of firms to raise monitored external finance depends upon their net worth and hence a decline in the net worth of bank dependent firms is likely to reduce both bank lending and corporate investment and other expenditures. The role of banks as suppliers of monitored finance introduces a further, complementary, channel of monetary transmission. As discussed in Holmstrom and Tirole (1997) banks themselves must have sufficient capital in order themselves to have an incentive to undertake such monitoring. This in turn suggests that fluctuations in the level of bank capital can generates a shifts in bank loan supply that further amplify and propagate the business cycle.

Analysis of this second channel of macroeconomic propagation should take account of the fact that bank capitalisation is an endogenous choice variable. How is this to be done? One possible approach is to follow the example of Diamond and Rajan (2000) extending standard models of bank monitoring by introducing a trade-off between capital issue (protection against shocks) and deposit finance (protection against opportunistic behaviour by the bank exploiting uninformed shareholders), thus determining optimal bank capital decision. The difficulty with this approach for modelling monetary policy is that it is technically difficult to model capital dynamics in such a setting. In a recent paper, Christiano, Motto and Rostagno (2007) have taken a step to this direction. They introduce financial intermediaries (banks) into DSGE model with monetary policy. In their model, the banks make loans to firms by which they finance working capital. The banks also hold excess reserves as an input to the production of demand deposit services. These reserves, and thus the bank's balance sheet, also play a role in bank interest rate determination.

Our analysis draws instead on recent more stylised 'inventory' models of bank capital, exploring the dynamics of bank capital around such their optimal level, without explicitly addressing the various capital market frictions that lead banks to hold capital.[8] These models recognise that as a result of capital market frictions it can be costly for banks to recapitalise. Market or credit losses, or rapid balance sheet expansion, can temporarily reduce bank capital below desired levels and thus lead to restrictions in the supply of bank loans. A number of empirical studies suggest that deterioration of bank earnings or bank net worth restrain lending in the manner consistent with these models.[9]

We also allow for the presence of a 'cost channel' ie that possibility that bank and market interest rates directly affect marginal costs of production, as well as altering inter-temporal trade-offs in consumption and investment. This means that the immediate impact of higher interest rates, just like any other cost shock, is to increase prices and inflation and only subsequently, through the impact of output on inflation, does a monetary tightening lead to

[8] There is now a fairly large literature of such models including Passmore and Sharpe (1994), Baglioni and Cherubini (1994), Calem and Rob (1996), Froot and Stein (1998), Milne and Whalley (1999), Milne (2002), Heuvel (2002), Milne and Whalley (2003), Milne (2004), Heuvel (2004), Estrella (2004), Puera and Keppo (2006) and Zhu (2006).

[9] For example Houston, Marcus and James (1997), Peek and Rosengreen (2000), Milne, Robertson and Tang (2006).

a reduction of inflation. The cost channel is central to our analysis because, as we have already discussed, otherwise optimal choice of monetary policy fully offsets the bank lending channel in a standard New Keynesian model.

This cost mechanism appears to have been first formally modelled in 'limited participation' models of monetary policy, for example in Fuerst (1992) who assumes that producers borrow (from banks) in order to finance their current wage bill, before receiving revenues from sales with the consequence that reductions of real interest rates associated with a monetary expansion leads to an increase in output and economic activity.[10] The mechanism has been elaborated in several recent dynamic general equilibrium models of the 'cost channel'.[11] We adopt a reduced form specification that borrows on the main insight of this literature, that interest rates impact directly on marginal costs and hence on inflation. However, while this mechanism is now widely recognised, its quantitative magnitude and the relative importance in the cost channel of bank loan rates compared to market rates are not well established. We will show that the impact of the bank lending channel is very sensitive to assumptions about these parameters.

3 The model

This section presents our reduced form model of monetary policy with three state variables, y (the log deviation of output from its steady state level $\bar{y}$), inflation π (the deviation of inflation from its target level $\bar{\pi}$) and b (the deviation of the buffer of bank capital from its long run target proportion of bank assets $\bar{b}$). It also discusses the determination of model parameters. The model is solved using standard linear-quadratic techniques (described in Appendix).

[10] Fuerst (1992) makes this assumption so as to obtain real effects of monetary policy in a model in which prices are flexible but cash holdings are predetermined, preventing bond market interest rates affecting the demand for money. As a result expansionary open market operations (exchange of money for bonds) result in a decline in real bond interest rates. This 'limited participation' can also explain the liquidity effect of monetary policy on bond prices modelled also for example by Grossman and Weiss (1983), Rotemberg (1984), and Lucas (1990). Limited participation does not however on its own offer an entirely plausible account of monetary policy transmission. For a critique see Williamson (2005).

[11] Barth and Ramey (2001) revive the argument for such a cost-channel, presenting evidence that prices in at least some US 2-digit industries respond positively following a surprise tightening of monetary policy. The cost channel has since been introduced into a number of structural macroeconomic models including those of Rabanal (2003), Lawrence J Christiano and Evans (2005), Olover huelsewig and Wollmershaeuser (2006), Kaufmann and Scharler (2006) and Ibrahim Chowdhury and Schabert (2006).

3.1 State equations and model solution

The evolution of output and interest rates are described by the following reduced form macro-monetary model. This is a standard New Keynesian specification adapted to include a role for the banking sector and specifically for the constraining effects of bank capital buffers on bank lending.

The time period is quarterly. Output y_t is the log-difference of quarterly output from its steady state value. The capital buffer b_t is the ratio of beginning of period accounting bank net worth to bank assets (assets could be rescaled by a Basel type risk weighting, but doing so would not alter our results, since these risk-weightings do not alter markedly over short time periods). Interest and inflation are all quarter on quarter but expressed at annualised rate (eg $i_t = 0.04$ represents the rate of interest on funds invested in the market at time t until $t+1$ at a 4% annual rate of return or 1% quarter on quarter). All variables are deviations from steady state values.[12] Interest rates are determined at the beginning of each period and credited at the beginning of the following period.

The monetary policy objective is a choice of a path for interest rate $\{i_{t+k}\}_{k=0}^{\infty}$ that minimises the intertemporal quadratic loss function

$$\min_{\{i_{t+k}\}_{k=0}^{\infty}} \frac{1}{2} E_t \sum_{k=1}^{\infty} \delta^k \left[\pi_{t+k}^2 + \lambda y_{t+k}^2\right] \tag{3.1}$$

subject to constraints 3.2–3.5 describing the evolution of the economy. δ is policymaker's subjective discount factor and λ is relative weight attached to output gap target. The welfare theoretic foundations of this type of objective functions are laid down in Woodford (2003). Our objective function in 3.1 is written in terms of weighted quadratic deviations of inflation and output from their respective steady state values. Given the backward looking nature of output and inflation equations discussed below, the welfare theoretically consistent criteria would be to consider quasi-differenced inflation and output. However, above criteria still characterises the essential features by which different policy options can be ranked. Finally, in solving the optimal path for interest rate, we consider both discretionary and commitment solutions to the minimisation of this objective function.

Macroeconomic behaviour is described by the following state equations for output and inflation

$$y_t = \alpha_0 y_{t-1} + \alpha_1 y_{t+1|t} - \alpha_2 \left(i_t - \pi_{t+1|t}\right) - \alpha_3 \left(r_t - \pi_{t+1|t}\right) + \eta_t \tag{3.2}$$

and

$$\pi_t = \beta_0 \pi_{t-1} + \beta_1 \pi_{t+1|t} + \beta_2 i_t + \beta_3 r_t + \beta_4 y_t + \varepsilon_t \tag{3.3}$$

[12] In steady state we suppose that banks have market power and earn positive net interest income from the margin between loan rates and market rates. But we are concerned only with the deviations from steady state, so in steady state our model variables r and i both equal zero.

$\pi_{t+1|t}$ and $y_{t+1|t}$ denote expectations of inflation and output for the period $t+1$, given information available at time t. η_t and ε_t denote demand and cost-push shocks that are assumed to be drawn from mean zero normal distribution with variance σ_η and σ_ε. i_t and r_t are the rate of interest of bank lending and the short term market rate respectively. The banking sector holds a buffer of capital above the minimum capital required capital ratio, denoted by a third state variable b_t evolving according to the linearised state equation

$$b_t = \gamma_0 b_{t-1} + \gamma_2 i_{t-1} + \gamma_3 (r_{t-1} - i_{t-1}) + \gamma_4 y_{t-1} \tag{3.4}$$

Finally the mark up of the loan interest rate r_t over market interest rates responds to deviations in the bank capital buffer[13]

$$r_t - i_t = -\mu b_t \tag{3.5}$$

This setup differs from standard reduced form macro-monetary models in the following respects:

- It distinguishes the short term market rate of interest (i_t) – the policy variable – from the rate of interest on bank lending (r_t). In the standard setting real market interest rates affect aggregate demand by altering intertemporal trade-offs in consumption and investment ($\alpha_2 > 0$). Our setting allows for the possibility that these trade-offs are also affected by real bank lending rates ($\alpha_3 > 0$).
- As well as these standard impact of interest rates on demand the model includes the 'cost-channel' impact of interest rates on the marginal costs of production, both through short term market borrowing (β_2) and through bank borrowing (β_3).
- Bank loan rates are affected by b_t – the beginning of period ratio of bank capital (measured on an accounting basis) to total banks assets.
- b_t is itself affected by previous period output y_t (through its impact on loan demand and loan quality) and by previous period interest rates (through their impact on bank net interest income). Over time banks adjust their dividend payment policy to restore b_t back towards to long run target levels.

3.2 Calibration

We calibrate the model to the usual quarterly observation period for macroeconomic modelling. The baseline parameter values together with alternative parameter values are shown in Table 3.1. The values for α_0, α_1, β_0, β_1 and β_4 are similar to those emerging from many estimated New

[13] We have also experimented with alternative specifications in which loan rates are smoothed over time, rather than adjusting immediately to changes in y_t and b_t, and in which output has an additoinal direct demand impact on bank loan rates.

Keynesian dynamic general equilibrium models. We set β_0 and β_1 to be consistent with the microfounded model of Calvo pricing and complete price indexation. Details of the model's derivation are provided for instance in Woodford (2003) and in Christiano, Eichenbaum and Evans (2001). Giannoni and Woodford (2003) has estimated the closely related Phillips curve for the US albeit without allowing for any cost channel ie with the assumption that $\beta_2 = \beta_3 = 0$. Also, again in line with the New Keynesian macromodels, we set the elasticity of inflation with respect to output gap β_4 equal to 0.05. This is within the rather wide range of estimates reported in the literature, for example roughly two times higher than the value estimated Rotemberg and Woodford (1999) but about one third that implied by the estimates reported in Lawrence J Christiano and Evans (2005). Note that log deviations in marginal costs are proportion to, but perhaps three times larger than, log deviations in the output gap and so that the elasticity on marginal costs is around three times smaller than that on the output gap.[14]

Table 3.1 **Parameter values**

Parameter	S Standard model	C-LI Loan channel via demand only	C Cost channel	B1 Loan channel via demand	B2, Basel I Loan channel via demand and supply	A1 Basel II	A2 Basel II & higher capital buffer	Interpretation
δ	0.99							Quarterly discount factor
λ	0.05							Preference weight on output
α_0	0.75							Inertia of demand
α_1	0.25							Forward looking component of demand
α_2	0.50	0.30	0.50	0.30	0.30	0.30	0.30	Market interest rate semi-elasticity of demand
α_3	0.00	0.20	0.00	0.20	0.20	0.20	0.20	Loan interest rate semi-elasticity of demand
β_0	0.50							Inertia of inflation
β_1	0.50							Forward looking inflation
β_2	0.00	0.00	0.033	0.033	0.00	0.00	0.00	Cost channel via market interest rate
β_3	0.00	0.00	0.00	0.00	0.033	0.033	0.033	Cost channel via loan interest rate
β_4	0.05							Elasticity of inflation with respect to output
γ_0	0.70							Inertia of capital buffer
γ_2	0.00875							Market rate impact on capital buffer
γ_3	0.00175							Loan rate impact on capital buffer
γ_4	-0.20					0.20	0.20	Output impact on capital buffer
μ	1.50						0.75	Capital buffer elasticity of loan interest rates
σ_η	0.0093							Standard deviation of demand shocks
σ_ε	0.01							Standard deviation of cost-push shocks

In our model, the specification of aggregate demand equation is close to the standard specification derived from microfounded model of habit persistence in consumption. The difference is that there are now two interest rates – bank loan rates as well as the market interest rate – that affect aggregate demand. To ensure parameterisation consistent with such a model, we impose

[14] See Ravenna and Walsh (2006) eqn (15) page 205. The relationship between log deviations of output and marginal cost is the sum of the intertemporal elasticity of consumption and of leisure, which under standard parameterisations is about three.

the assumption that the sum of the two impacts (market interest rates and bank loan rates) on aggregate demand is in line with these models of habit persistence, ie that $\alpha_2 + \alpha_3 = 0.5$[15]. For simulations with no bank lending channel $\alpha_2 = 0.5$ and $\alpha_3 = 0$. Whenever we introduce a bank lending channel we assume that $\alpha_2 = 0.3$ and $\alpha_3 = 0.2$.

We have reviewed the wide range of magnitudes in recent papers on the cost channel.[16] We have chosen a parameterisation towards the upper end of those in this literature assuming, throughout our simulations, that the total impact of interest rates on marginal cost (the cost channel) is parameterised with $\beta_2 + \beta_3 = 0.0333$ ie an impact around twice our assumed impact of marginal costs on inflation.[17] We compare two different specifications of the impact of loan rates on the cost channel. The first is a 'balanced' specification with $\beta_2 = 0.0167$ and $\beta_3 = 0.01067$ ie loan rates and market rates play an approximately equal impact on both the cost channel. The second is an 'unbalanced' baseline in which $\beta_2 = 0$ and $\beta_3 = 0.0333$. ie we assume that the cost channel operates entirely through bank loan rates.

The behaviour of the bank capital buffer b_t over time depends upon the accumulation of net worth from after tax income, the growth of bank assets, and on the adjustment the capital buffer back towards its long run desired level through its decisions over the growth of loans and other assets and through the payment of earnings to shareholders ie the dividend payout ratio. We assume that each quarter this adjustment corrects the bank capital buffer back 30% towards its long run level, ie the inertia in the bank capital buffer is set equal to $\gamma_0 = 0.7$. The remaining coefficients in this equation, γ_2, γ_3, and γ_4 capture the short run impact of output and interest rates on the capital buffer.

The level of output has two different impacts on the bank capital buffer. Periods of rapid output growth are associated with increased loan demand and hence with a decline in the bank capital buffer as the growth of loan assets outstrips bank net worth. At the same time higher output growth reduces loan losses and hence increases bank earnings and the ratio of bank capital to bank assets. Empirical models of bank capital buffer dynamics suggest that in most periods this first effect dominates so that bank capital ratios move counter-cyclically. We therefore assume that the impact of output on capital buffers is negative with $\gamma_4 = -0.2$. This is in line with estimated empirical

[15] Woodford (2003, ch. 5) shows that the corresponding elasticity is equal to $(1 - \beta\eta)\sigma$, where η is the degree of habit persistence and σ is the intertemporal elasticity of consumption, in the microfounded New Keynesian model with habit persistence. Assuming $\sigma = 2$ and $\eta = 0.75$ and $\beta = 0.99$ yields $\alpha_1 + \alpha_2 = (1 - .99 * 0.75) * 2 = 0.515$

[16] Most cost channel models calibrate the contribution of the cost channel by assuming this is the same as that of marginal costs on inflation. Exceptions are Ravenna and Walsh (2006) who use GMM estimation and report (Table 1 page 207) coefficients on the cost channel (relative to those on marginal costs) varying from 1.239 to 11.831. Much lower estimates are reported by Rabanal (2003) using Bayesian estimation, with values of 0.24 for the US and 0.17 for the Euro area.

[17] Further evidence of an important cost channel impact is found in Gaiotti and Secchi (2004) who report that, for firms that reset prices rapidly within a large panel of Italian firms, product prices are increased within one year by enough to fully compensate for any changes in the cost of bank finance of working capital.

models of bank capital buffer dynamics.[18] As for the calibration of the relevant shocks, we refer to Woodford (2003, p. 345). He notes that the standard error of (annualised) residuals of the estimated IS curve in Rotemberg and Woodford (1999) model is 3.72 per cent. We translate this into our quarterly setup, such that the standard error of demand shock σ_η is set equal to 0.93%. We set the standard error of the cost-push shock equal to 1%.

The evolution of the capital buffer also depends upon the level of market and bank interest rates in the previous quarter, through their impact on bank net interest income. In most countries (the US is an exception) bank interest income tends to increase as market rates of interest rise. This is because of the presence of unremunerated liabilities, both transactions deposits and equity capital, typically around 20% of the balance sheet. Our baseline reflects this situation, assuming on the asset side of the balance sheet that 15% of total assets are fixed interest rate loans and bonds, 75% are adjustable rate loans, 10% are short term marketable assets carrying the market rate of interest, and 5% are unremunerated. On the liability side we assume that 20% of liabilities are unremunerated, 65% are remunerated at an adjustable rate that moves with bank lending rates, and the remaining 15% of liabilities are funded at market rates of interest. These parameterisations then implies that the *annual* bank net interest income expressed as a proportion of total assets (h_t), can be expressed follows

$$h = 0.75\, r_{t-1} + 0.10 i_{t-1} - 0.65 r_{t-1} - 0.15 i_{t-1} = +0.10 r_{t-1} - 0.05 i_{t-1} \quad (3.6)$$

The corresponding expression for the impact of interest rates on bank net income included as part of our state equation for b_t is $\gamma_2 i_{t-1} + \gamma_3 (r_{t-1} - i_{t-1})$. Here the parameters are quarterly, not annual, and we distinguish an interest rate level effect γ_2 from an interest margin effect γ_3. Assuming that the rate of tax on bank net interest income is 30% so post-tax income is 0.7× pre-tax income, we then have the parameterisation $\gamma_2 = (0.10 - 0.05) \times 0.7/4 = +0.00875$ and $\gamma_3 = +0.10 \times 0.7/4 = +0.0175$.[19]

In order to simulate the impact of the introduction of the new Basel II accord we alter the coefficient value of output on the capital buffer. Under the new accord (which will apply to all banks in Europe but only the largest banks in the US) bank capital requirements will be reduced when output is above trend and credit quality improves, while they will be increased when output is below trend and credit quality deteriorates. We assume a level of cyclicality that is slightly greater than reported in the various quantitative impact studies conducted by the Basel committee. Specifically, we impose the assumption that regulatory bank capital requirements are reduced by 0.4% of total assets when output gap rises by 1%. Since a increase in the regulatory

[18] Jokipii and Milne (2006), using annual data for European banks, find lagged coeffients in the range 0.2 to 0.4, consistent with a coefficient on the quarterly lagged variable of bettween 0.6 and 0.9. They report estimated coeffients on current output of -0.1. These estimates are comparable to those found in other studies.

[19] We also investigated an alternative 'US' parameterisation, with a much higher proportion of fixed interest rate lending, so as to allow for the different institutional arrangements in the US where fixed interest rate lending is relative important. This is alternative is discussed alongside our other simulation results below.

bank capital requirement results in a one for one reduction in the capital buffer this implies that the coefficient γ_4 alters from -0.2 to $\gamma_4 = -0.2 + 0.4 = +0.2$.

A difficult parameter to determine is μ measuring the direct impact of a change in the capital buffer on loan interest rates. To obtain some idea of the scaling involved, we note that bank equity capital, as a proportion of total bank assets, is typically 3–4% greater than minimum regulatory requirements. Therefore a decline in b from steady state value of 0 to -4% corresponds to a reduction in the equity capital of the entire banking sector to below its regulatory minimum, a severe systemic banking crisis resulting in both increased loan interest margins and probably also considerable non-price rationing of lending. In our model however this loan rationing must be captured entirely through an increase in the loan interest rate. We assume $\mu = 1.5$, implying that the reduction of capital to minimum regulatory levels increases effective loan margins by 6 percentage points.[20]

In discussing the monetary policy impact of Basel II, we will also consider how far the cyclical impact can be offset by the likely increase the steady state value of the regulatory capital buffer (a consequence that is likely to follow from the operation of the Pillar 2 requirements of the new accord for supervisors to review the capital planning of banks and ensure that they have enough capital to cope with the cyclical variability of minimum requirements introduced by the new accord).[21] We deal with this possibility in a fairly simple manner, assuming that when the target capital buffer is doubled (this does not itself affect the simulations since we measure b_t relative to the target) the impact of deviations of the capital buffer from target on the lending rate r_t is halved so that now $\mu = 0.75$.

4 Equilibrium responses and optimal policy

Our principal findings reported in Subsection 4.1 concern the different responses of output and inflation to a demand and cost-push shocks, when there is a bank lending channel, comparing cases when it operates through a conventional demand side interaction and when it also operates through the cost channel via marginal costs of production (most of these findings are illustrated in Figures 4.1–4.3). We then go on in Subsection 4.2 to examine the impact of making bank capital regulation more cyclical (illustrated in Figures 4.4–4.5) and the consequences of an exogenous shock to bank capital. These subsections report only the results obtained under the assumption that

[20] This supply impact can be compared to that reported by Milne et al (2006) Table 4, where a 4% decline of the capital buffer induces a decline in bank lending of 20 percent over one year.

[21] The various quantitative impact studies conducted by the Basel committee reveal that the new accord will reduce aggregate minimum capital requirements, with the main reductions being given banks with large mortgage portfolios. The individual capital assessments on the other hand will raise target capital buffers, so the overall imapct on actual bank capital remains uncertain.

monetary policy is optimised under discretion.[22] Finally in Subsection 4.3 we compare intertemporal losses arising in these different cases, under both discretion and commitment.

4.1 The dependence of the bank lending channel on the cost channel

Figure 4.1 reports the impact of a demand shock under *five* different specifications of the impact of interest rates on output and inflation. The first point to be taken from this figure is that in the absence of a cost channel monetary policy can fully offset the bank lending channel. Compare the outcome under the first of these specifications, the standard model with neither a bank lending nor a cost channel (assuming $\alpha_2 = 0.5$, and $\alpha_3 = \beta_2 = \beta_3 = 0$), with the outcome under the second specification, where there is now a bank lending channel but still no cost channel (assuming $\alpha_2 = 0.3$, $\alpha_3 = 0.2$, and $\beta_2 = \beta_3 = 0.$). These are the superimposed horizontal lines in the panels for output and inflation in Figure 4.1 ie in both of these cases monetary policy makers can fully offset demand shocks and output and inflation remain constant.

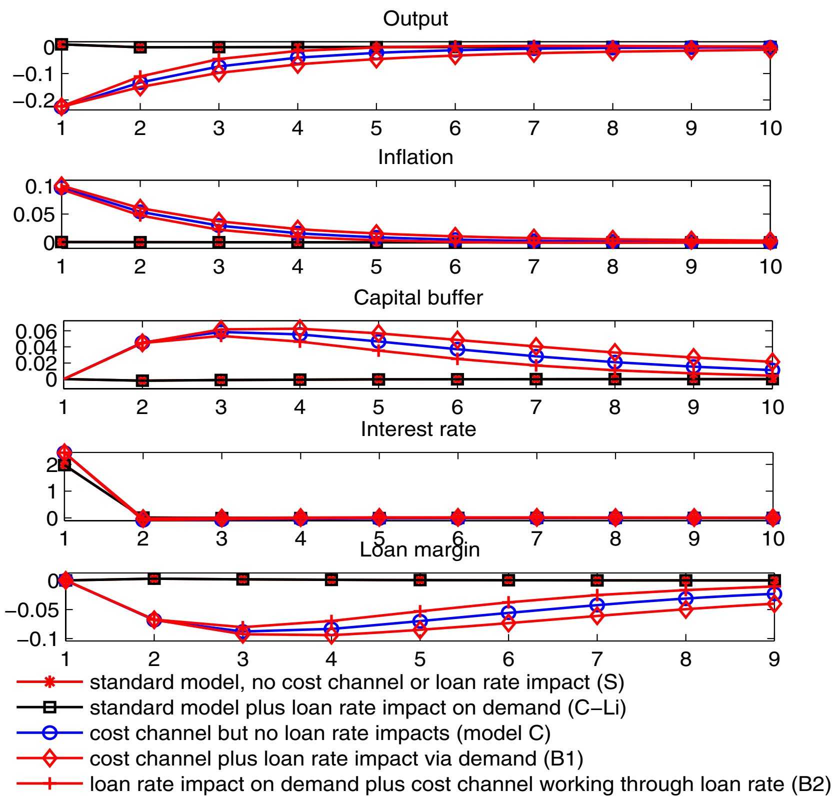

Figure 4.1 **Loan rate channel under demand shock**

[22] We obtained essentially the same results when monetary policy operates with commitment.

A similar result obtains in the case of a cost-push shock (although this is not illustrated in our figures). Policy makers can never fully offset a cost-push shock, they now face a trade-off and must accept some increase in inflation and loss of output. However output and inflation still follow identical paths under these two specifications (the standard model and standard model plus bank lending channel operating through aggregate demand). Policy makers are able to fully offset the bank lending channel and achieve the same outcomes for output and inflation under both specifications.

This is our first main finding. If there is no cost channel of monetary policy transmission the monetary authorities can always fully offset the impact of bank capital and bank loan margins on aggregate demand by choosing an appropriate level for market interest rates. For example as bank capital buffers increase and loan margins fall the impact of lower bank lending rates on aggregate demand can be fully offset by an appropriate additional tightening of monetary policy through higher market rates of interest (see Figure 4.1). As a result the bank lending channel has no effect on output-inflation trade-offs, under either demand or supply shocks.[23]

This is essentially the same result at that reported by Cecchetti and Li (2005), who show in a similar macro-monetary setting to our own that cyclical changes in bank capital regulations can be fully offset by altering the stance of monetary policy. We find that this is a more general result, policy makers can offset all output and inflation impacts of the bank lending channel not just of bank capital regulation.

What about when there is cost channel, ie when interest rates increase the marginal costs of production and as a result alter current inflation rates ($\beta_2 + \beta_3 > 0$)? As a result policy makers are no longer able to fully offset demands shock. As shown by the third line in Figure 4.1 (a cost channel simulation ($\alpha_2 = 0.5, \beta_2 = 0.0333$) with no bank lending channel ($\alpha_3 = \beta_3 = 0$) ie our model C) a positive shock to output of 1% is then met with a fairly large increase of interest rates, of around 2.25%. The outcome is that inflation rises fairly moderately, by 0.1% while output falls by about 0.225%. Thereafter output and inflation gradually converge back to their steady state levels.[24]

If we now introduce a bank lending channel into this setting, where there is a cost as well as a demand channel of monetary policy transmission, then the result is a change in output-inflation trade-offs; however the sign of this impact is ambiguous, a bank lending channel may either improve or worsen output-inflation tradeoffs depending on the relative importance of bank loan

[23] This is not to say that policy makers can entirely ignore the bank lending channel. It will still be important from an operational perspective that they understand its current and likely future impact on aggregate demand; and there are likely to be distributional impacts from the bank lending channel that need to be taken into account when presenting monetary policy decisions.

[24] We do not report results in detail, but we also found that the cost channel worsens output inflation tradeoffs relative to the standard model, following a supply shock as well as following a demand shock. With our parameterisation and a shock the same as that assumed for Figure 2, first period output falls 3.3% with the cost channel and 3.0% without the cost channel, while inflation rises 1.4% with the cost channel and 1.2% without. Output and inflation impacts in subsquent periods are also greater with a cost channel.

rates in determining output and inflation. In any case this further impact of the bank lending channel on output and inflation is rather smaller than that created by the introduction of the cost channel.

These findings are illustrated in the two remaining cases presented in Figure 4.1. These make a common assumption about the impact of the bank lending channel on aggregate demand ($\alpha_2 = 0.3$, $\alpha_3 = 0.2$), while imposing two different assumptions about the impact of bank lending channel on marginal costs. The first case is where there is no impact of bank loan rates on marginal costs ($\beta_2 = 0.0333$, $\beta_3 = 0$) ie our baseline model B1. In this case the bank lending channel worsens monetary policy trade-offs, since output declines lead to increased capital buffers and lower bank loan margins from period 2 onwards. As a result policy makers then need to impose a larger rise of market rates of interest to achieve any given reduction in aggregate demand, but in so doing firms face increased marginal costs that feeds into higher inflation. The outcome is that monetary policy makers accept a somewhat lower output and higher inflation from period 2 of the shock onwards.

The final case illustrated in Figure 4.1 is the opposite one where only bank loan rates and not market rates, affect marginal costs ($\beta_2 = 0$, $\beta_3 = 0.0333$) ie our baseline model B2. We think this situation is slightly more plausible than B1 with no bank loan rate impact on marginal costs, because working capital is financed predominantly from bank lending not market borrowing and therefore the bank lending channel should have a relatively larger impact on marginal costs than on aggregate demand.[25] Figure 4.1 shows that following a demand shock the bank lending channel now improves monetary policy trade-offs. The reason is again straightforward: the output decline leads to increased capital buffers and lower bank loan margins from period 2 onwards, and these in turn lower marginal costs and reduce inflation and allow the policy maker to respond somewhat more aggresively to the demand shock. As a result the policy maker can achieve slightly lower inflation and higher output from period 2 onwards under model B2, compared to the situation in model C when there is only a cost channel.

The bank lending channel has a similar impact on output-inflation trade-offs following a supply shock (Figure 4.2) as following a demand shock (Figure 4.1). A difference between these two figures is that following a supply shock the output impact is a good deal larger than those resulting from a demand shocks (output declines by over 3% following a standardised supply shock (Figure 4.2) compared with 0.2% for a standardised demand shock (Figure 4.1)). Once again the impact of the bank lending channel on output-inflation trade-offs depends on the relative importance of the bank loan rates for aggregate demand and for marginal costs.

When bank loan rates affect only aggregate demand and not marginal costs (ie model B1 rather than B2) then, compared to the pure cost channel (model C in which there is no impact from bank loan rates), the policy makers must accept a somewhat larger fall of output and rise of inflation from period 2

[25] The assumption that bank lending finances working caital is also made by Christiano et al (2006) and in fact, in many other models that feature financial intermediation and working capital.

onwards; so once again the output-inflation trade-off has worsened.[26] When bank loan rates and not market rates affect marginal costs (model B2) then the policy makers can achieve a somewhat smaller fall of output and rise of inflation from period 2 onwards. In both cases these effects arise because the decline of output leads to an increase in the bank capital buffer and hence a reduction in bank loan rates relative to market rates at the time when policy makers are raising interest rates in order to reduce inflation.

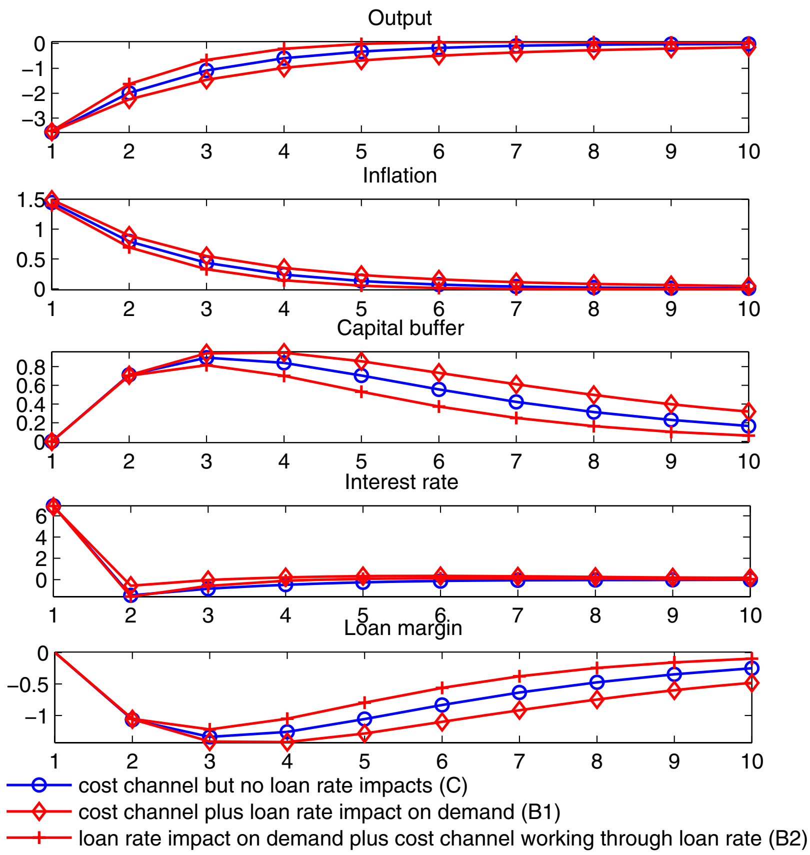

Figure 4.2 **Loan rate channel under cost-push shock**

The intuition from Figures 4.1 and 4.2 carries forward to other comparable simulations. For example we have considered an alternative simulation with $\alpha_2 = 0.3$, $\alpha_3 = 0, 2$, and $\beta_2 = \beta_3 = 0.0167$, and $\beta_3 = 0.0333$ (a balanced version of our baseline models). Now the aggregate demand and marginal cost channel impacts are roughly offsetting and the outcome is very close to that obtained under the pure cost channel (model C).

We also explored the impact of the bank-lending channel with different weightings on the output and inflation policy objectives. These results are reported in the efficiency frontiers[27] depicted in Figure 4.3. In this figure we

[26] As we have already pointed out, this effect depends on the presence of a cost channel. When there is no cost channel at all $\beta_2 = \beta_3 = 0$ then any impact of bank loan rates on aggregate demand ($\alpha_3 > 0$) can be fully offfset by the monetary authorities.

[27] We are indebted to Ulf Söderström for his suggestion to use efficiency frontiers in the analysis.

let the central bank's weight on output change from 0 (strict inflation targeting) to 0.1 (moderate weight on output variability) representing small perturbation from our baseline weight of 0.05. This shows that our qualitative conclusions do not depend upon the weighting given to the output objective. Output-inflation trade-offs are unaffected by introducing the bank lending channel into the standard model without a cost channel. If there is a cost channel (model C) then the introduction of a bank lending channel always either worsens (model B1) or improves (model B2) the monetary policy trade-off.

Figure 4.3 also reveals that the impact of the bank lending channel on output inflation tradeoffs (the shifts in the tradeoffs from model C to model B1 or model B2) measured by their distance from the origin are smaller than the impact of the cost channel on output-inflation tradeoffs (the shift in the tradeoff from model S to model C).

We draw two further conclusions from this Figure. First we note that with the introduction of the cost-channel, the monetary policy maker can no-longer fully offset the impact of cost and demand shocks on inflation. Even when there is zero-weight on output, ie the extreme right-hand points on the efficiency frontiers, the variance of inflation is greater than zero. This is why with a low weighting on output the trade-offs in the presence of the cost channel (the cost channel alone C and the cost channel combined with the two bank lending channel specifications B1 and B2) lie well above the trade-off when there is no cost channel. We also observe, unsurprisingly, that the impact of the bank lending channel on intertemporal losses is very small when the policy maker places a low weight on output variability. In this case the policy maker can achieve a very similar outcome for inflation, with or without a bank lending channel. But if the policy maker places a relatively high weighting on output variability, then the impact of the bank lending channel on inflation variability and hence on intertemporal losses is much greater.

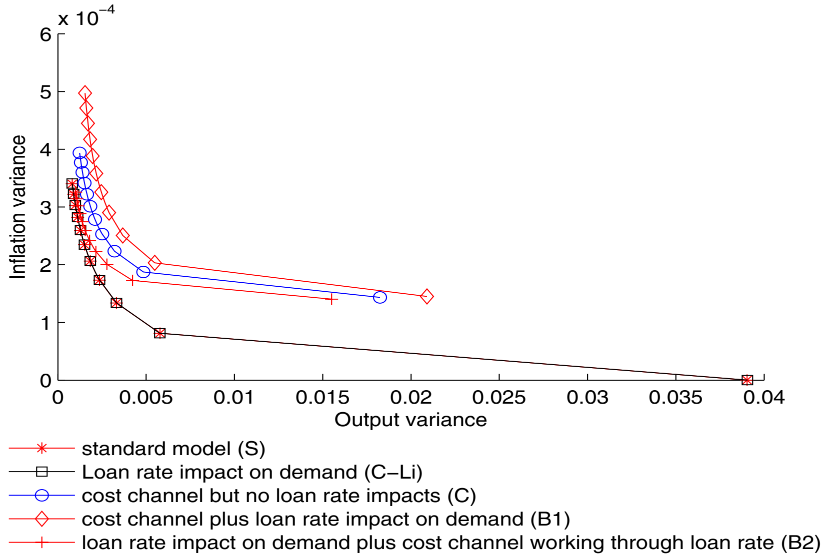

Figure 4.3 **Efficiency frontiers under different model specifications**

4.2 The impact of Basel II and of shocks to bank capital

Our next two figures (Figures 4.4 and Figure 4.5) analyse the impact of cyclical variability in bank capital regulation, arising from the introduction of the new Basel II accord, both under a demand and a supply shock. Throughout these figures we use the baseline B2 from Figures 4.1–4.2 assuming $\alpha_2 = 0.3$,$\alpha_3 = 0.2$, and $\beta_2 = 0$, and $\beta_3 = 0.0333$. We consider first the introduction of Basel II compared with the existing Basel I. With the introduction of cyclically varying capital requirements under Basel II capital buffers now move pro-cyclically in the face of both supply and demand shocks, declining from period 2 onwards because of the reduction in output. As a result loan interest rates increase relative to market rates and the resulting impact on marginal costs leads to a deterioration in output-inflation trade-offs. Output is lower and inflation is higher from period 2 onwards.

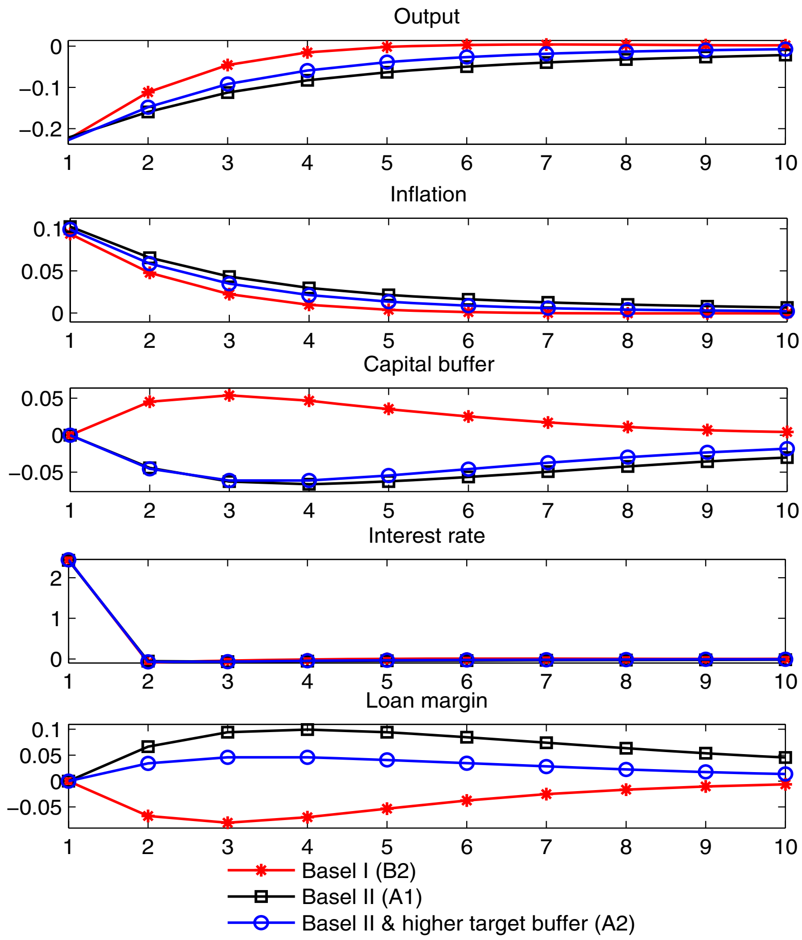

Figure 4.4 **Cyclically-varying Basel II capital requirements: demand shock**

The impact is quantitatively much larger in the case of a supply shock, where period 2 output is nearly 1% lower under Basel II than under Basel I and inflation is almost 0.5% higher, compared with a period 2 loss of output of about 0.04% and higher inflation of 0.02% following a demand shock, but in both cases the period 2 loss of output and increase of inflation are about two fifths greater under Basel II regulation than under Basel I. We find that the impacts, while going in the same direction as those reported in Figures 4.4 and 4.5, are very much smaller under our balanced baseline B1, the period 2 loss of output and rise of inflation being only around one-twentieth larger under Basel II as under Basel I.

Policy makers have suggested that any undesirable macroeconomic impact of the new Basel accord can be offset by using Pillar II supervisory review, and in particular the review of internal capital assessments (ICAP), encouraging banks to hold larger target levels of capital and managing their capital through the business cycle so they do not breach regulatory minimum requirements. The final simulations in Figures 4.4 and 4.5 capture this mechanism by reducing the impact of capital buffer shortfalls on bank loan margins (reducing μ from 1.5 to 0.75). This is appropriate since with larger capital buffers the sensitivity of loan rates to fluctuations in the capital buffer will be reduced. We find that under our baseline model B2 this reduction partially but not entirely offsets the deterioration in output inflation trade-offs.

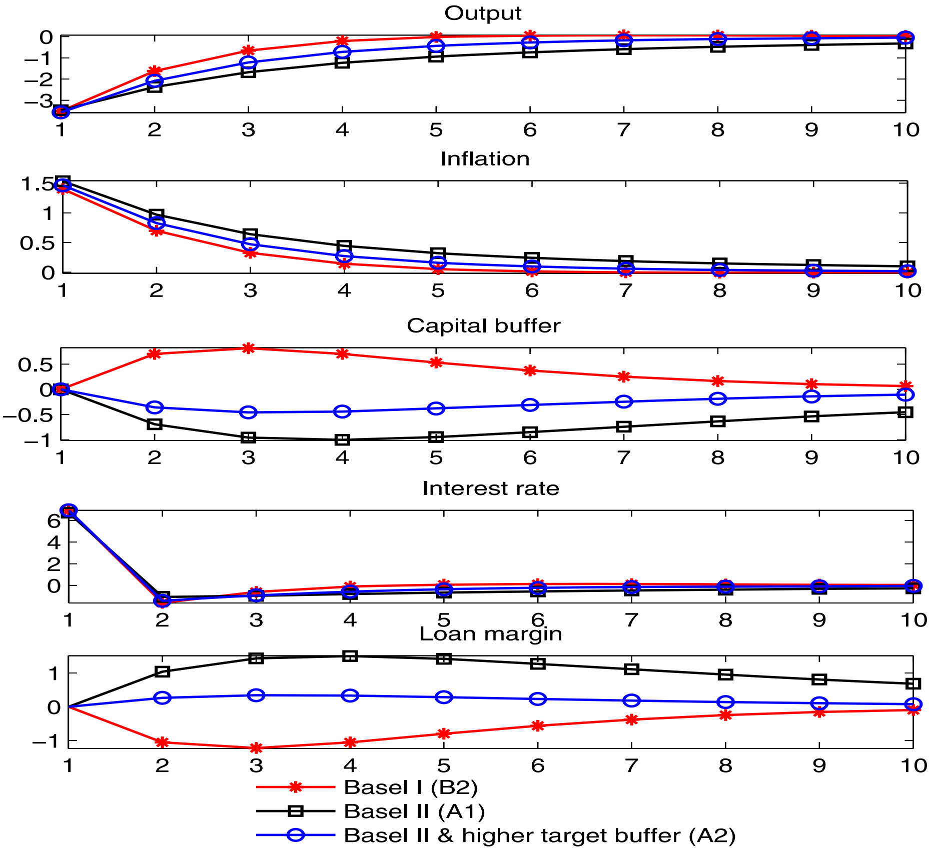

Figure 4.5 **Cyclically varying Basel II capital requirements: cost push shock**

The intuition behind these results is once again straightforward. As we have already shown with the baseline model B2 and Basel I capital rules, fluctuations in bank capital serve to offset the impact of the cost channel, reducing bank loan rates and hence reducing the impact of the cost channel during periods when market interest rates are increased and hence improving output inflation trade-offs. In contrast, under Basel II, bank capital fluctuations increase bank loan rates when market rates are increased and hence exacerbating the impact of the cost channel. Introducing larger capital buffers and lower sensitivity of interest rates to the capital buffer weakens this cost channel impact of bank loan rates, but cannot fully restore the beneficial impact of the bank lending channel obtained under the Basel I regulations.

We have also explored the consequences of an exogenous decline in the bank capital buffer, such as occurred in for example in the early 1990s in Japan and Scandinavia and more recently amongst banks exposed to sub-prime mortgage backed securities. We find that policy makers respond to such a decline in bank capital with a reduction in the market rate of interest ie there is an accomodative loosening of monetary policy. This is because the reduction of bank capital buffers results in an increase of bank loan rates and this change of interest rates faced by households and firms reduces output below its equilibrium level.

In the setting where there is no cost channel monetary policy makers are able to fully offset this shock to bank capital. The outcome is more complicated in the case of our baseline B2 when bank loan rates contribute to the cost channel. Now a decline in bank capital also operates through marginal costs, at the same time both increasing the rate of inflation and reducing the level of output. In this situation policy makers are still accommodative, but they are unable to avoid some decline in output and increase of inflation. We also find that the impact of a shock to the capital buffer is similar under both Basel I and Basel II. If banks hold higher levels of capital buffers to offset the Basel II pro-cyclicality of capital requirements, then the magnitude of the impacts on both output and on inflation are reduced.

4.3 Further analysis of intertemporal losses

In this sub-section, in order to highlight the differing costs caused by regulatory changes under different assumptions of cost channel, we evaluate the intertemporal loss function given in (3.1).[28] As before we assume first that policy is conducted under discretion. The first column of table 4.1 shows the intertemporal loss under different assumptions of cost channel and regulatory framework. The following 3 columns measure the cyclical variation of the economy by means of unconditional standard errors. Our first observation is that introduction of cost channel increases the volatility of inflation, output and capital buffer: this is simply due to the fact that the policymaker needs to trade-off some output variability for inflation variability when there is a cost channel operating through market interest rates.

Second, we observe that when market interest rates work through intertemporal trade-offs and bank loan rates work mainly through marginal costs, the behaviour of loan margins mitigate the effects of cost channel (compare models C and B2). This is due to the counter-cyclical movements in bank capital buffers which leads to lower bank loan rate margins when output and interest rates are below the steady state.

Finally we amend model B2 to take account of the new capital regulations being introduced through the Basel II accord, and the resulting pro-cyclical movement in capital buffers. Now changes in loan margins exaggerate rather than mitigate the impact of the cost channel and the policy maker is forced to accept more output and inflation variability. This results in a substantial increase in costs in comparison to Basel I. Allowing for a larger capital buffer and hence a smaller impact of changes in the capital buffer on loan margins slightly improves the situation, restoring about half the loss introduced under Basel II.

[28] We also repeated these calculations introducing small shocks to the capital buffer itself. This merely increases the volatility of output. Given that output has a small weight on intertemporal loss criteria, our basic results in terms ordering of different regimes remains intact.

Table 4.2 **Intertemporal loss and state variable volatility under discretion**

	Loss	Cyclical variation - standard errors		
		Output	Inflation	Capital buffer
Standard model	0.030	0.039	0.015	0.017
Cost channel only (model C)	0.038	0.043	0.017	0.018
Loan channel via demand (B1)	0.045	0.047	0.019	0.022
Basel I (B2)	0.033	0.039	0.016	0.015
B2, with Basel II (model A1)	0.052	0.050	0.020	0.024
A1, with larger buffer (model A2)	0.043	0.046	0.018	0.021

Table 4.2 shows the equivalent results when the policy is conducted under commitment. In the standard model with no cost or loan channels commitment allows policy makers to achieve a much lower variability of inflation, compared to the results obtained under discretion. The impact on loss, relative to the standard model, of introducing the cost channel and the lending channel are very similar under commitment and under discretion. Loss increases with the introduction of the cost channel but then improves under our baseline model B2 (because the bank lending channel then offsets the cost channel), and once again increases when Basel II is imposed on this baseline (but to a smaller degree than when the policy maker operates with discretion.)

Table 4.2 **Intertemporal loss and state variable volatility under commitment**

	Loss	Cyclical variation - standard errors		
		Output	Inflation	Capital buffer
Standard model	0.024	0.045	0.012	0.021
Cost channel only (model C)	0.031	0.044	0.015	0.020
Loan channel via demand (B1)	0.034	0.048	0.015	0.023
Basel I (B2)	0.028	0.040	0.014	0.016
B2, with Basel II (model A1)	0.036	0.051	0.016	0.025
A1, with larger buffer (model A2)	0.033	0.047	0.015	0.022

5 Discussion and conclusions

There is a large literature on the bank lending channel suggesting that bank balance sheets and lending rates can have a major impact on the transmission mechanism of monetary policy. But this literature for the most part takes a partial equilibrium perspective and fails to address the extent to which monetary policy makers can respond to offset the impact of the bank lending channel on output and inflation. The objective of this paper has been to address this issue, examining the impact of the bank lending channel on output inflation trade-offs in a New Keynesian macroeconomic model of optimal monetary policy.

Our main conclusion is that, with reasonable parameter assumptions, the bank lending channel has only a fairly small impact on output-inflation trade-offs. Extending an insight of Cecchetti and Li (2005), we find that the response of output and inflation to both demand and supply shocks are completely unaffected by the bank lending channel, as long as interest rates operate entirely through the conventional route via intertemporal trade-offs and aggregate demand. In this situation policy makers can always offset the impact of the lending channel on output and inflation by an appropriate adjustment of interest rates, both in response to supply or demand shocks.

We find that the bank lending channel can alter output-inflation trade-offs *if* there is also a cost channel ie if interest rates alter marginal costs and thus directly impact on inflation, as well as affecting the economy through aggregate demand. The presence of a cost channel means that demands shocks can no longer be fully offset by policy makers and supply shocks are rather greater than they would otherwise be. Following either a demand or a supply shock, policy makers increase interest rates and output falls. But if interest rates affect marginal costs as well as aggregate demand, then it is also possible for the margin between bank loan rates and market rates of interest, as well as the level of interest rates, to affect output and inflation.

The sign and magnitude of the resulting bank loan channel impact on output and inflation depends upon the relative contribution of bank loan rates, in comparison to market rates, on aggregate demand and on marginal costs. If bank loan rates have a relatively large impact on aggregate demand and relatively small impact on marginal costs, then larger increases in interest rates are required to achieve a given reduction of aggregate demand and output-inflation trade-offs deteriorate ie the bank lending channel amplifies the cost-channel. In the reverse and we believe more plausible situation, where bank loan rates have a relatively large impact on marginal costs and relatively small impact on aggregate demand, then output-inflation trade-offs improve ie the bank lending channel offsets the cost-channel. In either case the quantitative magnitude of these bank lending channel impacts on output-inflation tradeoffs are clearly less than the impact of the cost-channel, our simulations suggesting their impact on achievable output and inflation is about one half those of the cost-channel.

We further show that *if* the bank lending channel does indeed lead to an improvement on output inflation trade-offs through its amelioration of the cost channel *then* the same bank loan rate cost-channel interaction means that the introduction of pro-cyclical capital requirements such as those of Pillar 1 of the new Basel II accord results in a worsening of output-inflation tradeoffs, even when monetary policy response responds optimally, and that this worsening is quantitatively much larger than the improvement in output-inflation tradeoffs resulting from the operation of the bank lending channel under the old Basel I accord. We reach this conclusion, directly opposite to that of Cecchetti and Li (2005), because in our setting bank loan rates play a particularly important role in the cost-channel and as a result the impact of pro-cyclical bank capital requirements on bank loan rates cannot be fully corrected through adjustment of market rates. We also find that the better management of bank capital buffers through the business cycle, promoted by Pillar 2 of the new Basel accord, offsets much but not all of this Pillar I deterioration in output inflation tradeoffs.

While our model elucidates the impact of the lending channel and of bank capital requirements on output-inflation trade-offs, there are several reasons for believing that this impact is likely to be rather smaller than reported in our simulations, at least within the normal range of macroeconomic fluctuations. First our results are predicated on a quantification of the cost channel that is towards the upper end of the range of estimates found in the literature. While there is no consensus on the magnitude of the cost channel it is quite possible that it is smaller than we have assumed and hence that our simulations overstate the impact of the bank lending channel on output inflation trade-offs. Second there is no strong reason for believing that bank loan rates have such a relatively large imapact on marginal costs and relatively small impact on intertemporal tradeoffs, compared to market rates as we assume in our baseline B2. If the relative impact of bank loan rates and market rates on aggregate demand and on marginal costs are similar then the bank lending channel makes little difference to macroeconomic outcomes. Third, it maybe that our parameterisations exaggerate somewhat the degree of counter-cyclical fluctuations in bank capital ratios, especially in banking systems such as the US where banks conduct a relatively large amount of fixed interest rate lending. Introducing this relationship into our model, the rise of interest rates following a macroeconomic shock would reduce bank interest income and hence lead to less pronounced cyclical fluctuations in bank capital buffers than we report here.

Finally we show that, under what we believe to be the most plausible assumption that bank loan rates have a relatively large impact marginal costs, an exogenous shock to bank capital has a macro-economic impact rather similar to a cost (ie inflation) shock; it leads to a loss of output and rise of inflation which cannot be fully offset through adjustment of monetary policy ie our model replicates at least some of the output losses which have been found to follow declines in bank capital. There are however good reasons for believing that the output losses following a major depletion of banking sector capital will be larger than predicted by these model simulations. The linear quadratic framework of this paper, designed as it is for analysing relatively small deviations in output and inflation about their long-run values which must be controlled by monetary policy actions, is not ideal for addressing concerns about financial stability. In a systemic crisis, when bank balance sheets are severely depleted, the output and inflation impacts of bank net worth may be very much larger than those obtained in the linear-quadratic framework.

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Appendix
State space representation of the model

Our model consists of following 4 equations, as discussed in the main text

$$
\begin{aligned}
y_t &= \alpha_0 y_{t-1} + \alpha_1 y_{t+1|t} - \alpha_2(i_t - \pi_{t+1|t}) - \alpha_3(r_t - \pi_{t+1|t}) + \eta_t && \text{(A1.1)}\\
\pi_t &= \beta_0 \pi_{t-1} + \beta_1 \pi_{t+1|t} + \beta_2 i_t + \beta_3 r_t + \beta_4 y_t + \epsilon_t && \text{(A1.2)}\\
b_t &= \gamma_0 b_{t-1} + \gamma_2 i_{t-1} + \gamma_3(r_{t-1} - i_{t-1}) + \gamma_4 y_{t-1} && \text{(A1.3)}\\
r_t &= i_t - \mu b_t && \text{(A1.4)}
\end{aligned}
$$

Moving the equation for the capital buffer (A1.3) one period forward and re-ordering the variables so that the predetermined variables are written first. This yields

$$
\begin{aligned}
\eta_{t+1} &= \rho_\eta \eta_t + v_{\eta,t+1} \\
\epsilon_{t+1} &= \rho_\eta \epsilon_t + v_{\epsilon,t+1} && \text{(A1.5)}\\
r_t &= i_t - \mu b_t && \text{(A1.6)}\\
b_{t+1} &= (\gamma_0 - \gamma_3 \mu)\, b_t + \gamma_4 y_t && \text{(A1.7)}\\
-\alpha_3 r_t + \alpha_1 y_{t+1|t} + (\alpha_2 + \alpha_3)\, \pi_{t+1|t} &= y_t - \alpha_0 y_{t-1} + \alpha_2 i_t - \eta_t \\
\beta_3 r_t + \beta_1 \pi_{t+1|t} &= \pi_t - \beta_0 \pi_{t-1} - \beta_2 i_t - \beta_4 y_t - \epsilon_t
\end{aligned}
$$

Denoting the predetermined state variables (including the laws of motion for the stochastic disturbances) by a vector $z_{t+1} = \{\eta_{t+1}, \epsilon_{t+1}, r_t, b_{t+1}, y_t, \pi_t\}$, the forward looking state variables by the vector $x_{t+1|t} = \{y_{t+1|t}, \pi_{t+1|t}\}$ and the control variable by i_t, we can express the model in the following matrix form

$$
E \begin{pmatrix} z_{t+1} \\ x_{t+1|t} \end{pmatrix} = A \begin{pmatrix} z_t \\ x_t \end{pmatrix} + B i_t + C_u \begin{pmatrix} v_{t+1} \\ 0 \end{pmatrix}
$$

Following (A1.7) the elements of matrices E, A, B and C_u are defined as follows

$$
E = E = \begin{pmatrix}
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & -\alpha_3 & 0 & 0 & 0 & \alpha_1 & (\alpha_2 + \alpha_3) \\
0 & 0 & \beta_3 & 0 & 0 & 0 & 0 & \beta_1
\end{pmatrix}
$$

$$
A = \begin{pmatrix}
\rho_\eta & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & \rho_\varepsilon & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\mu & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & (\gamma_0 - \gamma_3 \mu) & 0 & 0 & \gamma_4 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\
-1 & 0 & 0 & 0 & -\alpha_0 & 0 & 1 & 0 \\
0 & -1 & 0 & 0 & 0 & -\beta_0 & -\beta_4 & 1
\end{pmatrix}
$$

$$B = \begin{pmatrix} 0 & 0 & 1 & 0 & 0 & 0 & \alpha_2 & -\beta_2 \end{pmatrix}'$$

and finally C_u matrix is

$$C_u = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{pmatrix}$$

Post-multiplying A and B and C by the inverse of E, we arrive into standard state space model:

$$\begin{pmatrix} z_{t+1} \\ x_{t+1|t} \end{pmatrix} = \tilde{A} \begin{pmatrix} z_t \\ x_t \end{pmatrix} + \tilde{B} i_t + \tilde{C}_u \begin{pmatrix} v_{t+1} \\ 0 \end{pmatrix} \qquad \text{(A1.8)}$$

where $\tilde{A} = E^{-1}A, \tilde{B} = E^{-1}B$, and $\tilde{C} = E^{-1}C$. Given (A1.8), we can then express periodic quadratic loss function in terms of the state variables z_t and x_t. In our case, periodic loss function L_t simply reads as

$$L_t = Y_t' W Y_t \qquad \text{(A1.9)}$$

where

$$Y_t = C_1 \begin{pmatrix} z_t \\ x_t \end{pmatrix}$$

and where C_1 is selector matrix and W is appropriate diagonal weighting matrix given below:

$$\begin{aligned} C_1 &= \begin{pmatrix} \mathbf{0}_{1\times 6} & 1 & 0 \\ \mathbf{0}_{1\times 6} & 0 & 1 \end{pmatrix} \\ W &= \begin{pmatrix} 1 & 0 \\ 0 & \lambda \end{pmatrix} \end{aligned}$$

Standard solution algorithms can then be used to minimise discounted sum of L_t and at the same time solving for rational expectations equilibrium (See for instance Söderlind, 1999, and Svensson and Woodford, 2003). We have used an amended version of software originally written by Gerali and Lippi, 2003.

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