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The macroeconomic effects of a stable funding requirement*

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Abstract

This paper examines the macroeconomic effects of a stable funding requirement of the type proposed under Basel III and introduced by the Reserve Bank of New Zealand in 2010. The paper sets out a small open economy model incorporating a banking sector with disaggregated liabilities, and a tractable setup for multi-period debt allowing for hedging of benchmark interest rate risk. A stable funding requirement attenuates credit expansion if funding costs rise more steeply with volumes in long-term markets. However, the requirement amplifies the pro-cyclical effects of fluctuations in bank funding spreads. During systemic funding market stress, greater exposure long-term markets exacerbates deleveraging and recession, despite lower aggregate rollover, because long-term markets are more affected and long-term spreads are carried for longer. Such amplification increases in the level of the requirement and the net external debt. We conclude that adverse macroeconomic outcomes can be moderated with suitable policy design.

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1 Introduction

In periods when credit has grown rapidly, retail deposits have tended to grow more slowly and banks have shifted toward short-term wholesale funding. The shift to short-term wholesale funding, rather than more stable longer-term wholesale or retail funding reflects the lower cost of short-term funding and banks' access to central bank liquidity during crises that leads banks to underinsure against refinancing risk (moral hazard). As discussed in Shin and Shin (2011) the shift toward short-term wholesale funding increases the exposure of the banking system to refinancing risk both through increased rollover requirements and also through the lengthening of intermediation chains associated with funding from other financial institutions.

Reliance on short-term wholesale funding increased banks' vulnerability to funding market closure during the global financial crisis (GFC). In response, extensive liquidity support was provided to banks (reinforcing moral hazard), and stronger liquidity regulation has been proposed to increase banks' ability to endure prolonged liquidity crises.

The liquidity regulation proposed under Basel III[1] sets out stable funding requirements -- a net stable funding ratio (NSFR) and a core funding ratio (CFR) respectively[2] -- as well as liquid asset requirements and maturity mismatch limits.[3] While the two stable funding requirements differ in their details, they are similar in overall effect: banks will need to raise more stable funding in the form of retail deposits or long-term wholesale funding.

The contribution of this paper is threefold: (i) it sets out a general equilibrium model featuring a bank with disaggregated liabilities (retail deposits, and short- and long-term external wholesale funding); (ii) it sets out a tractable

[1] http://www.bis.org/bcbs/basel3.htm. The net stable funding requirement is scheduled to come into force in 2018. Similar liquidity regulation was introduced by the Reserve Bank of New Zealand in 2010. See http://www.rbnz.govt.nz/finstab/banking/. A core funding requirement was announced in October 2009, introduced in April 2010 and increased in July 2011.

[2] In this paper, we use the terms stable funding and core funding interchangeably to mean retail deposits plus long-term wholesale funding. In contrast, Shin and Shin (2011) consider funding raised from other financial institutions to be "non-core" because of the systemic risk associated with long intermediation chains.

[3] Other approaches to liquidity regulation include a liquidity overlay on capital regulation (see, for example, Brunnermeier et al (2009)), and price-based approaches such taxes that offset distortions (Pigouvian taxes). Shin (2010) considers a tax on non-core funding. Kocherlakota (2010) proposes market-based pricing of macro-prudential taxes. Perotti and Suarez (2011) compare tax and balance sheet approaches.

setup for multi-period funding that (unlike the usual fixed-rate setup) allows the bank to shed benchmark interest rate risk.[4]; and (iii) in this general equilibrium framework, it examines the macroeconomic effects of a stable funding requirement and potential means of mitigating adverse outcomes.

In general, a stable funding ratio is estimated to moderate both the steady-state level of debt and the dynamic growth of credit. The introduction of a stable funding requirement increases funding costs because (i) long-term funding is more expensive than short-term funding and (ii) as retail deposits become explicit substitutes for relatively expensive long-term funding they are paid a stability premium. Higher retail deposit and loan interest rates imply higher savings, lower investment and lower net external debt. The dynamic slowing of credit expansion arises because funding costs rise with volumes more steeply in less-liquid long-term funding markets than in short-term funding markets and because rising long-term funding costs are passed through to retail deposit interest rates when deposits are explicit substitutes for long-term funding.

The stable funding requirement, however, amplifies the response to fluctuations in wholesale funding spreads (spreads between long-term funding costs and the rollover of short-term funding). Wholesale funding spreads, and long-term wholesale spreads in particular, tend to be compressed during credit booms and to expand during systemic funding market stress (see Figure 1). The stable funding requirement amplifies the pro-cyclical effect of funding spreads for two reasons. First, the requirement increases the required rollover in long-term markets (Figure 2), increasing banks' exposure to long-term markets, despite the lower rate of rollover overall. Second, long-term funding spreads matter doubly for the bank because they are larger than short term spreads (see Figure 1 and Acharya and Skeie (2011) for a theoretical discussion), and must be carried for the duration of the funding (they cannot be hedged). The exposure to long-term funding spreads and the extent of deleveraging and recession in the face of an adverse funding spread shock is increasing in the levels of the stable funding requirement and the net external debt.

We find that buffers held by banks above the minimum requirement and state-dependent variation of the requirement can help to moderate adverse macroeconomic outcomes. Our results support the idea of a counter-cyclical stable funding requirement (eg. macro-prudential overlay) for the same reasons that support a counter-cyclical capital overlay: to avoid high costs of

[4] In practice, banks carry little interest rate risk. See Craigie (forthcoming) for an empirical study of interest rate risk for Australian and New Zealand banks

meeting the requirement in a crisis and to facilitate use of buffers that have been built up in good times.

The rest of the paper is set out as follows: Section 2 provides a brief review of the literature. Section 3 sets out the model, and its properties with and without a stable funding requirement. Section 4 considers the attenuating effect of a stable funding requirement on credit expansion. Section 5 examines the amplification of wholesale funding market spreads, and considers the roles of ex-ante buffers and ex-post forbearance in mitigating adverse outcomes, and counter-cyclical application of the requirement. Section 6 examines sensitivity of the results to key parameters. Section 7 concludes.

2 Literature review

The paper relates to three strands of the literature. The first is the fast-growing literature that explicitly incorporates financial intermediation into DSGE models.[5] Goodfriend and McCallum (2007) consider the roles of interest rate spreads in monetary policy analysis in a model with money and a banking sector. Christiano et al (2010) and Meh and Moran (2010) apply credit frictions of Bernanke et al (1999) to bank balance sheets. Kato (2006) and Covas and Fujita (2010) employ the financial imperfections of Holmstrom and Tirole (1998) that emphasise the liquidity provision role of banks. In a model with heterogenous banks, Gertler and Karadi (2011) introduce agency problems between banks and savers that lead to liquidity shortages and consider the roles of credit policies and bank recapitalisation. Gertler et al (2011) capture the moral hazard of such credit policies and consider macro-prudential policies that can offset the distortion ex-ante. Gerali et al (2010) introduces a bank with sticky retail loan and deposit rates and endogenous bank capital accumulation. De Walque et al (2010) employ the 2-period model of Goodhart et al (2005) that features interbank markets and endogenous default, and consider capital regulation and liquidity injections. This paper introduces a disaggregated bank liability structure, including retail deposits and long-term debt dynamics, to assess the macroeconomic effects of a stable

[5] A large literature on financial frictions does this implicitly, focusing on the effect of collateral constraints on non-financial balance sheets. See Gertler and Kiyotaki (2010) for a review. Most of the papers in this literature are linear approximations around a deterministic steady state. Exceptions are Brunnermeier and Sannikov (2009), He and Krishnamurthy (2010) and Bianchi and Mendoza (2010) which feature occasionally binding constraints and episodes of financial instability in general equilibrium environments.

funding ratio and explore aspects of policy design.

Second, this paper contributes to the overlapping literature that assesses the effects of prudential policies. A large finance literature models responses to prudential policies. Some of these models feature endogenous risk taking among heterogeneous agents and provide rich, non-linear dynamics, but they are typically set in short-horizon, partial equilibrium models.[6] In contrast, a growing DSGE-based literature examines the role of prudential policies in a general equilibrium environment. Most of the models in this literature, like the one employed in this paper, are linear approximations around a deterministic steady state.[7] While they lack the dynamic richness of the nonlinear finance models, they benefit from more tractable solution methods and the general equilibrium environment. Such an approach is useful for examining the first-order macroeconomic effects of prudential policies, but less so for examining the underlying externalities and instability that motivate such policies. Many of the models in this literature examine capital requirements and loan-to-value ratios.[8] Those that deal with liquidity include Gertler and Kiyotaki (2010) which examines central bank liquidity provision and the role of liquid assets); Gertler et al (2011) which considers a tax/subsidy scheme with the flavour of a counter-cyclical capital requirement; and Roger and Vleck (2011) which examines a liquid asset ratio. In contrast, this paper examines the effects of a liability-side stable funding requirement.

Finally, the paper relates to the literature on modeling multi-period debt. Woodford (2001) introduced exponentially-decaying perpetuities in DSGE models as a tractable way of modeling multi-period debt with a single state variable. This approach has been widely used in the sovereign debt literature[9] and the finance literature.[10] Benes and Lees (2010) use a similar structure

[6] Recent papers that directly consider liquidity policies include Shin (2011), Farhi and Tirole (2009), Perotti and Suarez (2011), Segura and Suarez (2011) and He and Xiong (2009). See Jean (2011) for a review.

[7] Exceptions include Bianchi and Mendoza (2010) and He and Krishnamurthy (2010).

[8] For example, Van den Heuvel (2006) examines the role of capital requirements in a non-linear model; Lambertini et al (2011) examines the interaction between monetary policy and an LTV-based policy in a model with financial frictions for housing and firms and news-driven cycles. Angelini et al (2011) analyses the strategic interaction between monetary policy, macro-prudential capital requirements and LTVs for the Euro area in a model based on Gerali et al (2010).

[9] For recent examples, see Hatchondo and Martinez (2009), Chatterjee and Eyigungor (2010) and Eusepi and Preston (2010).

[10] Arellano and Ramanarayanan (2008) provide a discussion of the liquidity and commitment benefits of short-term debt and multi-period debt and their relationship to observed interest spreads.

in a DSGE model for fixed rate loans to households. While this approach is suitable for fixed-rate loans or fixed-rate sovereign bonds, it implies a large degree of interest rate risk (and associated valuation effects). Modern banks use interest rate swaps to hedge interest rate risk. Here we extend the perpetuity approach for long term debt to accommodate bank funding subject to a floating coupon plus a fixed-rate spread that cannot be hedged. This allows us to more realistically model the effects of multi-period bank funding.

3 Model

We develop a model of a profit-maximising bank that is set in an open economy RBC model. The open economy RBC model (Appendix A) is based on a representative household that provides labour and capital to firms and receives the profits of those firms. The household is a net debtor, but derives utility from holding deposits in the bank. The model is closed with a debt-sensitive risk premium. We introduce a bank that intermediates between households and external wholesale funding markets. The bank provides one-period loans to households, and raises three types of funding: one-period retail deposits, one-period wholesale funding, and multi-period bonds from external wholesale markets. Wholesale funding is subject to a funding spread that is increasing in the duration of the funding. Banks hedge benchmark interest rate risk. In contrast to non-financial firms, the bank is foreign-owned, so bank profits accrue to non-residents.

Setting the policy in a flexible price model allows us to focus on the effects of the stable funding requirement in the absence of offsetting monetary policy. While the interaction with monetary policy is important, we want to consider approaches to moderating adverse effects without pushing monetary policy into overdrive. Interaction with monetary policy is left for further work.

3.1 Household loan demand and deposit supply

As the bank both lends to private agents and raises retail deposits, gross loans and deposits (rather than simply net loans) need to be included in the model. Including deposits in the utility function provides a tractable way to achieve this.[11] The presence of deposits can be motivated by the liquidity value of deposits (cash balances) in lowering transaction costs where money (deposits) serves as a means of payment.[12] The representative household maximises expected utility:

$$\max_{C_t,N_t,L_t,D_t} E_t \sum_{t=1}^{\infty} \beta^{t-1} \left[log(C_t - hC_{t-1}) + \chi \frac{D_t^{1-\gamma}}{1-\gamma} - \nu \frac{N_t^{1+\sigma}}{1+\sigma} \right] \tag{1}$$

This set up yields the usual first order conditions (Appendix A) plus the following demand for deposits:

$$\chi \frac{1}{D_t^{\gamma}} = \left(1 - \frac{R_t^D}{R_t^L}\right) U'_{c,t} \tag{2}$$

Deposit demand is increasing in the retail deposit rate, decreasing in the retail loan rate (households use internal funds rather than borrow at high rates) and decreasing in the marginal utility of consumption (when the marginal utility of consumption is high and households hold fewer deposits so they can consume more).

3.2 Bank

For tractability and ease of exposition, it is useful to think of the bank as being comprised of four units:

- a retail lending unit;
- an aggregate funding unit that combines core- and non-core funding;
- a core funding unit combines retail deposits and long-term wholesale funding; and
- a retail deposit unit.

The aggregate balance sheet is shown below and flows between the units are illustrated in Figure 3.

[11] See Sidrauski (1967) for the seminal paper. In a DSGE model with a bank, De Walque et al (2010) include deposits in the utility function in a different functional form. Deposits can also be created by introducing patient households that deposit funds with the bank and impatient households that borrow from the bank as in Gerali et al (2010).

[12] For example, the cash-in-advance money models of Lucas and Stokey (1987) and Cooley and Hansen (1989). Kiyotaki and Moore (2008) argue, along the lines of Wallace (1998), that money should arise as a contractual solution, and present a model where money serves a liquidity role.

Assets	Liabilities
Retail loans (90-day)	90-day wholesale funding (non-core) 5-year wholesale funding (core) 90-day retail deposits (core)

.

Retail loan and deposit units

Retail loans and deposits are assumed to be a basket of differentiated contracts produced by banks with market power. Differentiated contracts are combined with elasticity of substitution ϵ^L and ϵ^D respectively. This Dixit-Stiglitz framework captures the existence of monopolistic competition in retail banking.[13] The demand for an individual bank's contract depends on the bank's interest rate relative to average rates in the economy. The demands for loans and deposits, derived from individual household's cost minimisation, and aggregated across households, are:

$$L_t(j) = \left(\frac{r_t^L(j)}{r_t^L}\right)^{-\epsilon^L} L_t \qquad D_t(j) = \left(\frac{r_t^D(j)}{r_t^D}\right)^{-\epsilon^D} D_t \tag{3}$$

With this setup, profit maximisation leads the retail lending unit to lend funds to households at a fixed markup on the average cost of funds, r_t^l, where the markup reflects the bank's market power. Similarly, the retail deposit unit pays retail depositors a fixed markdown on the marginal value of the deposit, r_t^d:

$$r_t^L = \frac{\epsilon^L}{\epsilon^L - 1} r_t^l \qquad r_t^D = \frac{\epsilon^D}{\epsilon^D - 1} r_t^d \tag{4}$$

In a perfectly competitive market, (large ϵ^L, ϵ^D), the markup/markdown becomes very small.

As retail loans are one-period, there is no reason (apart from the stable funding ratio) for the bank to raise multi-period funding. The implication of this in the model is that the bank offers households loans at a markup on its average cost of funds. If we had a matching multi-period set-up on the lending side (banks issue long-term loans at fixed- or floating-rates and swap the income stream for floating rate payments) with the same duration, then households would make marginal decisions based on the marginal cost of bank funding

[13] Introducing monopolistic competition may seem strange in an RBC context. We do this to achieve a constant markup that covers the banks fixed costs. In the absence of a markup, the retail deposit rate (the marginal cost of stable funding with a stable funding ratio) would be higher than the retail loan rate which is an average of the short-term wholesale rate and the higher cost of stable funding.

with considerably larger effects on loan demand in response to more volatile funding costs. Suppose a retail mortgage has a maturity of 25 years. In the absence of long-term guarantees (eg those provided by Fannie and Freddie in the US), loans are typically repriced several times within the mortgage maturity. Overlapping repricing of many mortgages means that loans priced at the bank's average cost of funding is likely a reasonable approximation of retail lending rates. It may even be that banks smooth lending rates by more than that implied by the average cost of funds, something we consider in section 6.

Aggregate funding unit

The aggregate funding unit combines core funding, B_t^c, with non-core funding, B_t^S, into a one-period loan, L_t, which is on-lent to the retail deposit unit. The aggregate funding unit chooses the quantities of core and non-core funding that maximise expected profits:

$$\max_{B_t^c, B_t^S} E_t \sum_{t=1}^{\infty} \beta^{t-1} \lambda_t^b \Big[B_t^c + B_t^S + (1 + r_{t-1}^l) L_{t-1} \\ - L_t - (1 + r_{t-1}^a) B_{t-1}^c - (1 + r_{t-1}^S) B_{t-1}^S - \tfrac{\kappa^{cfr}}{2} \left(\tfrac{B_t^c}{L_t} - \nu^{cfr} \right)^2 B_t^c \Big]$$

subject to the balance sheet constraint $L_t = B_t^c + B_t^S$ and the regulatory requirement embodied in ν^{cfr}, where r_t^a is the average cost of core funding paid to the core funding unit, r_t^S is the rate paid on one-period funding, and the term containing κ^{cfr} is a quadratic adjustment cost associated with deviating from the desired core funding ratio, ν^{cfr}. ν^{cfr} can be thought of as the bank's desired core funding ratio determined by internal risk management, by pressure from markets or by explicit regulation.

The first order conditions define the spreads between the average cost of funding r_t^l, and the cost of core and non-core funding.

$$r_t^l - r_t^S = -\kappa^{cfr} \left(\tfrac{B_t^c}{L_t} - \nu^{cfr} \right) \left(\tfrac{B_t^c}{L_t} \right)^2 \quad (5)$$

$$r_t^a - r_t^S = -\kappa^{cfr} \left(\tfrac{B_t^c}{L_t} - \nu^{cfr} \right) \tfrac{B_t^c}{L_t} \quad (6)$$

Combining (5) and (6), the interest rate on aggregate funding can be expressed as a weighted average of the benchmark rate, r_t, and the rate paid for core funding, r_t^a:

$$r_t^l = (1 - \tfrac{B_t^c}{L_t}) r_t + \tfrac{B_t^c}{L_t} r_t^a \quad (7)$$

Core funding unit

The core funding unit produces core funding, B_t^c, by combining one-period retail deposits, D_t, and multi-period bonds, $\tilde{B}_t^M$, and on-lends the funds to the aggregate funding unit at the average cost r_t^a. The balance sheet constraint is:

$$D_t + \tilde{B}_t^M = B_t^c \tag{8}$$

where D_t is retail deposits and $\tilde{B}_t^M$ is the stock of all outstanding bonds available to the core funding unit at time, t.

Systemic funding market stress is treated as exogenous in our open-economy setup. New bonds, B_t^M, issued at t are issued in external capital markets at the swap rate (the expected cost of rolling over funding at the 1-period benchmark rate) plus a funding spread (to swap) that is fixed at the time of issuance and cannot be hedged.[14]. The time-varying funding spread $m\ \tau_t$ is increasing in the duration of the funding m, consistent with observed spreads (Figure 1). τ_t evolves according to $\tau_t = \tau_{t-1}^{\rho^\tau} \bar{\tau}^{1-\rho^\tau} e^{\epsilon^{\tau_t}}$, $\epsilon^{\tau_t} \sim N(0, \sigma_t^\tau)$.[15] The cost of 1-period external wholesale funding ($m = 1$) is the benchmark rate plus a small external funding premium: $r_t^S = r_t + \tau_t$.

For tractability, it is useful to divide the bond repayments in two parts: (i) principal repayment plus a fixed coupon, and (ii) floating rate coupon payments. Repayment of principal and the fixed coupon on funding B_t^M raised at time t is paid at a decaying rate. This perpetuity structure is based on the set-up introduced in macro-models by Woodford (2001). Here we extend the setup for fixed-rate debt in Benes and Lees (2010) to include a floating coupon component. Total payments on debt raised at time t are as follows:

$$\begin{array}{ll} t+1: & (Q_t + r_t)B_t^M \\ t+2: & \delta^M (Q_t + r_{t+1})B_t^M \\ t+3: & (\delta^M)^2 (Q_t + r_{t+2})B_t^M \\ \vdots & \vdots \end{array}$$

where Q_t is the fixed payment related to principal and the fixed spread on long term debt raised at time, t. The sum of repayments of the principal plus the fixed spread on all past wholesale funding due at time t (excluding

[14] Fixed-coupon bonds are assumed to be swapped, with an external counterparty, to floating coupon bonds at the swap rate plus a fixed spread.

[15] τ_t is a highly skewed shock process.

floating interest payments) is

$$J_{t-1} = \sum_{k=1}^{\infty} (\delta^M)^{k-1} Q_{t-k} B^M_{t-k} \tag{9}$$

The law of motion of the decaying fixed payments, (9), can be written in recursive form:

$$J_t = \delta^M J_{t-1} + Q_t B^M_t \tag{10}$$

In this perpetuity setup, the book value of the principal declines at a rate δ^M, so that the law of motion of the stock of unmatured bonds $\tilde{B}^M_t$ is:

$$\tilde{B}^M_t = \delta^M \tilde{B}^M_{t-1} + B^M_t \tag{11}$$

Q_t covers the principal repayment $(1 - \delta^M)$ and the fixed component of the coupon payment:

$$Q_t = (1 - \delta^M + m\tau_t) \tag{12}$$

The duration of the funding is the present value of repayments weighted by time to maturity:

$$m = E_t \sum_{k=1}^{\infty} k(\delta^M)^{k-1}(Q_t + r_{t+k}) \left[\frac{1}{R^c_t \dots R^c_{t+k-1}} \right]$$

in steady-state,

$$m = \frac{R^c}{R^c - \delta^M}$$

The proceeds of bonds are on-lent to the aggregate funding unit at the average cost of core funding:

$$r^a_t B^c_t = r^c_t D_t + [J_t - (1 - \delta^M)\tilde{B}^M_t] + r_t \tilde{B}^M_t \tag{13}$$

Deposits and new bonds are paid at the marginal cost of core funding and unmatured long-term funding is paid at the benchmark plus previously contracted spreads.

The core funding unit chooses new core funding (D_t and B^M_t) to maximise the expected stream of future profits:

$$\begin{aligned} \max_{B^c_t, D_t, B^M_t, J_t, \tilde{B}^M_t} E_t \sum_{t=1}^{\infty} \beta^{t-1} \lambda^c_t \Bigg[& B^M_t + D_t + (1 + r^c_{t-1}) B^c_{t-1} \\ & - B^c_t - J_{t-1} - r_{t-1} \tilde{B}^M_{t-1} - (1 + r^d_{t-1}) D_{t-1} \\ & - \tfrac{\kappa^M}{2} \left(\tfrac{\tilde{B}^M_t}{\tilde{B}^M_{t-1}} - 1 \right)^2 B^M_t \Bigg] \end{aligned} \tag{14}$$

subject to the evolution of J_t (10) and the evolution of the stock of bonds $\tilde{B}_t^M$ (11), where r_t^c is the marginal cost of new core funding, and κ^M is a cost associated with changing the stock of multi-period funding raised in long-term wholesale markets.

At time t, the core funding unit receives funds lent to the aggregate funding unit at $t-1$ plus interest (r_t^c), proceeds of new bonds B_t^M and new deposits D_t. It repays the deposit unit with interest, repays maturing principal and interest on outstanding bonds issued before time t ($J_{t-1} + r_{t-1}\tilde{B}_{t-1}^M$), pays out profits, and pays adjustment costs.

The term containing κ^M represents a liquidity effect in bond markets. If outstanding bonds increase rapidly (new issuance exceeds maturing debt), the bank faces rising funding costs relative to increasing funding from short-term markets. We interpret this to reflect a stronger price response to volumes in less liquid long-term markets relative to short term markets.[16] [17] These adjustment costs imply that the supply of long-term funding is steep in the short run and flat in the long run. Adjustment costs associated with an increase in short- and long-term funding are already present in the debt-sensitive risk premium.

Assigning the $t+k$ budget constraint a Lagrange multiplier $\beta\lambda_{t+k}^c$, the law of motion for J_{t+k} a Lagrange multiplier $\lambda_t^c\Psi_{t+k}$, and the law of motion for $\tilde{B}_{t+k}$ a multiplier $\lambda_t^c\Phi_{t+k}$, the first order conditions[18] are:

$$B_t^c: \quad 1 = \beta E_t\left\{\tfrac{\lambda_{t+1}^c}{\lambda_t^c}(1+r_t^c)\right\} \tag{15}$$

$$D_t: \quad r_t^c = r_t^d \tag{16}$$

$$B_t^M: \quad 1 = \Psi_t Q_t + \Phi_t \tag{17}$$

$$J_t: \quad \Psi_t = \frac{1}{R_t^c}E_t\left\{(1+\delta^M\Psi_{t+1})\right\} \tag{18}$$

[16] Such a cost could also represent higher marketing/roadshow costs or perhaps issues around commitment to repay the debt, although the latter would imply an upward-sloping long-run supply curve. For example, Arellano and Ramanarayanan (2008) present a model where investors prefer short term funding for control reasons (debtors cannot commit to not increasing debt during the term of the funding), but provide a small amount of long term funding to reduce borrowers' liquidity risk.

[17] For New Zealand banks, such costs relate not only to net issuance in foreign debt markets, but also net issuance by swap counter-parties in NZD debt markets so that foreign currency funding is hedged.

[18] With adjustment cost to first order.

$$\tilde{B}_t^M: \quad \Phi_t = \frac{1}{R_t^c} E_t \Big\{ r_t + \delta^M \Phi_{t+1}) \Big\} + \kappa^M \left(\frac{\tilde{B}_t^M}{\tilde{B}_{t-1}^M} - 1 \right) \frac{B_t^M}{\tilde{B}_{t-1}^M}$$
$$- \frac{\kappa^M}{R^c} \left(\frac{\tilde{B}_{t+1}^M}{\tilde{B}_t^M} - 1 \right) \frac{B_{t+1}^M \tilde{B}_{t+1}^M}{\tilde{B}_t^M)^2} \tag{19}$$

According to (15) $1/R_t^c$, the unit discounts at the marginal return on assets. According to (16), the marginal cost of a unit of core funding equal to the cost of a one-period retail deposit.

According to (17), the marginal value of a bond is equal to the expected sum of repayments of principal and fixed rate coupon payments (on the fixed spread to swap), Ψ_t, plus the expected value of future floating rate interest payments, Φ_t. In a competitive equilibrium the present value of payments on B_t^M is equal to the value of the borrowing net of adjustment costs. Equation (17) can be understood by writing the total stream of payments on a bond B_t^M issued at time t as:

$$B_t^M = \underbrace{Q_t B_t^M E_t \sum_{k=1}^{\infty} \frac{(\delta^M)^{k-1}}{R_t^c \dots R_{t+k-1}^c}}_{\text{principal + fixed coupon payments}} + \underbrace{B_t^M E_t \sum_{k=1}^{\infty} \frac{(\delta^M)^{k-1} r_{t+k-1}}{R_t^c \dots R_{t+k-1}^c}}_{\text{floating coupon payments}}$$

so,

$$\Psi_t = E_t \sum_{k=1}^{\infty} \frac{(\delta^M)^{k-1}}{R_t^c \dots R_{t+k-1}^c}, \text{ and } \Phi_t = E_t \sum_{k=1}^{\infty} \frac{(\delta^M)^{k-1} r_{t+k-1}}{R_t^c \dots R_{t+k-1}^c} \tag{20}$$

According to (18) and (19) Ψ_t and Φ_t can be expressed recursively. Ψ follows directly from Benes and Lees (2010), while Φ allows the bank to shed interest rate risk. This set-up allows us to examine multi-period funding in an environment suitable for a modern bank that, through use of interest rate swaps, carries little benchmark interest rate risk.

For one-period funding ($m = 1, \delta^M = 0$) the set-up above reverts to the standard set-up.

Combining (16), (17), (18) and (19), the marginal value of 1-period retail deposits can be written as a function of the long-term wholesale spread:

$$r_t^d = r_t + m \left[\bar{\tau} + \tau_t \left(1 + \delta^M (1 - \rho^\tau) \Psi_{t+1} \right) \right] \tag{21}$$

The deposit rate is the benchmark rate plus a multiple of the wholesale spread that is increasing in the duration of the wholesale funding and increasing in the persistence of the spread. The term $(1-\rho^{\tau})$ captures the expected decay of the spread from period t to $t+1$ and δ^M captures the duration that the spread will need to be paid. Intuitively, the expected cost of raising core funding through issuing an m-period bond today equals the cost of raising a one-period retail deposit and issuing a slightly smaller (m-1) period bond next period, taking into account the smaller average funding spread and the expected evolution of the AR1 funding spread. If the term spread is high (which it is when markets are stressed), then the unit will be willing to pay considerably more for a retail deposit to put off raising term funding for another period if the final term in (21) is large. The pass-through from higher funding costs to higher lending rates depends on the share of core funding, the persistence of the high spread and the degree of competition in the retail funding and lending markets.

Bank aggregation

The bank's aggregate balance sheet constraint is,

$$L_t = D_t + \tilde{B}_t^M + B_t^S = D_t + B_t^e \tag{22}$$

Aggregate bank profits are,

$$\begin{aligned} \Pi_t^B &= \tilde{B}_{t-1}^M(1-\delta^M) - J_{t-1} + (r_{t-1}^L - r_{t-1})L_{t-1} + (r_{t-1} - r_{t-1}^D)D_{t-1} \\ &- \tfrac{\kappa^L}{2}\left(\tfrac{r_t^L}{r_{t-1}^L} - 1\right)^2 r_t^L L_t - \tfrac{\kappa^D}{2}\left(\tfrac{r_t^D}{r_{t-1}^D} - 1\right)^2 r_t^D D_t \\ &- \tfrac{\kappa^{cfr}}{2}\left(\tfrac{B_t^c}{B_t} - \nu^{cfr}\right)^2 B_t^c - \tfrac{\kappa^M}{2}\left(\tfrac{\tilde{B}_{t+1}^M}{\tilde{B}_t^M} - 1\right)^2 B_t^M \end{aligned} \tag{23}$$

In steady-state, bank profit is the spread between the loan rate and the benchmark rate plus the spread between the deposit rate and the benchmark rate less the fixed premia on external wholesale funding.

$$\Pi^B = (r^L - r)L + (r - r^D)D - \bar{\tau}B^S - (m\bar{\tau})\tilde{B}^M$$

In the absence of liquidity-related costs or a stable funding requirement, the bank would seek to shorten the duration of wholesale funding (here m is fixed) .

3.3 Model calibration

The calibration of the baseline open economy RBC model is fairly standard as shown in Table 1 with some adjustment to match New Zealand data.

The domestic discount rate is set at the standard 0.99 (annual 4% real interest rate). The inverse elasticity of labour supply is set at 1; other values are considered in the sensitivity section. The investment adjustment cost parameter υ is set at 0.07 so that investment is about 3.5 times as volatile as GDP in response to a technology shock. The parameter γ^D (the household deposit elasticity) is set at 3 so the standard deviation of deposits averages about 3 times that of GDP for the model shocks, consistent with New Zealand data. The debt-sensitive risk premium parameter of 0.0018 attributes the observed real interest differential of about 2% to a net external debt to GDP ratio of 80% of annual GDP. This is consitent with estimated values of 0.001 to 0.002 for New Zealand (see Munro and Sethi (2007) and Medina et al (2008)) and empirical studies (see (Laubach 2003) and (Haugh and Turner 2009)).

The duration of long-term funding, m, is set to 17 to match the duration of a 5-year bond that pays coupons each quarter and principal at maturity. The parameter ν^{cfr} is calibrated to fix the steady-state shares of B^S and $\tilde{B}^M$ to match the desired level, taking into account in the calibration the absence of bank capital and the residual maturity of the bonds (the last 3 quarters are non-core funding) and the buffer held by the bank above the regulatory minimum. [19] The steady-state spread on multi-period funding (eg term premium) is set to match the observed average of about 50 basis points for 5-year funding.

The retail deposit elasticity, ϵ^D, is set to 10, consistent with the average 40bp markdown on the benchmark rate $(r_t^S - r_t^D)$ observed for New Zealand data. This compares to values of 1.3 in Gerali et al (2010) based on European bank spreads. The retail deposit rate is a markdown on the short term rate in the benchmark model because the declining deposit share was matched by a rising share of short-term wholesale funding when credit grew rapidly (see Figure 4).

The retail loan elasticity, ϵ^L, is set to 4 consistent with the observed 200bp markup on marginal mortgage lending before 2008. This is within the (5.1 to 3.5) ranges calibrated in Gerali et al (2010) based on European bank spreads.

We have no prior estimates for the adjustment cost parameters κ^{cfr} and κ^M. κ^M is calibrated at 17 which is high (a 1% rise in net mew issuance leads to a

[19] This approach fits with the observed mix of bank funding, but the marginal cost of multi-period funding is equal for different levels of the CFR. An alternative approach would be to fix ν^{cfr} at a high level and alter the duration m of the funding to match the regulatory requirement.

discount of 80bp on the price of new bonds). This value is chosen to prevent negative new issuance; we consider $\kappa^M = 0$ in the sensitivity section.

For a given short-run slope of the supply of long-term funding, defined by κ^M, the value of κ^{cfr} is calibrated to yield a 5 percentage point fall in the core funding ratio in the face of a funding spread shock of the magnitude seen during the GFC (or about 1.5 percentage points for a 100bp shock to the funding spread). This is motivated by anecdotal evidence that, on average, New Zealand banks hold buffers of about 5 percentage points above the core funding requirement - and we assume the buffer will be fully used in such an event. This gives a value of $\kappa^{cfr} = 0.2$ and implies that a fall of 5 percentage points in the core funding ratio (below the bank's desired level to the minimum regulatory requirement) incurs a cost of about 50bp on the price of new core funding.[20]

Shock AR1 coefficients are set at 0.8, except the AR1 coefficient of the funding spread shock that is set at 0.875 to match the persistence of the observed 5-year spread.

3.4 Model properties

This section describes the changes from the standard RBC model, a ''benchmark'' model, and the introduction of a stable funding requirement and subsequent increases in the requirement.

Benchmark model

The benchmark model differs from a basic open economy RBC in three main ways. First is the introduction of deposits (equation A.5). On its own, this has no effect on the model dynamics except that it grosses up loans. Net loans behave exactly as in the model without deposits (money is a veil). This is the RBC model presented in the graphs.

Second, the introduction of long-term funding ($m > 1$) introduces rigidity in the model because the stock of term funding changes slowly. Because long-term funding spreads to benchmark are larger than short-term spreads and because those spreads must be carried for many periods, changes in the funding spread can have a large effect on the bank's desire to use long-term

[20] Of course, in practice, the costs are highly asymmetric and nonlinear: small if the buffer is ample, and very high as the bank approaches the minimum which, in New Zealand, is a condition of registration.

funding. As the stable funding requirement rises (ν^{cfr} or m increases), the bank is increasingly exposed to movements in long-term spreads.

Finally, the introduction of a CFR (implicitly imposed by markets/rating agencies or the bank's own risk management) of 65% which is consistent with the observed level of core funding of New Zealand banks before the introduction of the CFR.

Model with an explicit stable funding ratio

With the introduction of an explicit stable funding requirement, two things change relative to the benchmark model. First, deposits and multi-period wholesale funding become linked as substitute forms of stable funding. The profit maximising bank therefore equalises their marginal costs and the rate paid on deposits is the marginal cost of 5-year funding rather than 90-day funding.[21] The steady state effect on the retail deposit rate is 50bp. The steady state effect on the average cost of funds is about 25 basis points. Dynamic effects can be large. When the funding spread is high, the observed retail deposit spread may be higher than the observed long-term spread (equation 21, Figure 5).[22] In our setup with a stable funding requirement, the retail deposit rate is expected to settle at a markdown of about 50bp below the marginal cost of core funding -- so at about the benchmark rate (Figure 5).[23]

Second, the bank's desired core funding ratio increases by 5% because the bank chooses to hold a buffer above the regulated level. In the graphs a 65% regulated CFR is referred to as 65% CFR plus 5% buffer. Each 5% rise in the CFR increases the average cost of funds by a further 2.5bp.

The steady states of the benchmark and CFR 65% (+5% buffer) models are shown in Table 4. In this type of model, the steady state net external debt is fixed. As retail deposit and lending rates increase with the changes above, the external debt would be expected to fall. We do not capture the evolution of the net external debt in this type of linear open economy model. Indeed, out

[21] This assumption is debatable. In practice, banks may have paid a small markdown on the cost of short-term funding, or a larger markdown on the marginal cost of long-term wholesale funding. Estimation of the model may inform on the shift. See Appendix B for a discussion of retail deposit rate markdowns.

[22] The observed rise in the retail spread may also be the result of increased competition for deposits which would drive up deposit spreads beyond that implied by profit-maximising behaviour.

[23] This upward shift in deposit interest rates implies an increase in efficiency if moral hazard (central bank liquidity insurance) and monopolistic power have led to deposit (and so loan) rates that have not reflected their relative stability value to the bank.

calibrated deposit/GDP and deposit/loans ratios are held constant, implying that the supply of retail deposits is relatively interest inelastic and, in the long term, the requirements imply a larger share of long-term wholesale funding. In nonlinear models (see Bianchi and Mendoza (2010), even a small reduction in net debt can have large effects. While the higher steady-state retail interest rates imply a decline in net external debt for a small open economy, if all countries adopt macro-prudential policies that raise funding costs the implied rise in savings might translate into a lower world real interest rate rather than a decline in net debt (globally, imbalances must sum to zero). So the degree to which net external debt declines remains uncertain.

4 Credit expansion with a stable funding requirement

In the wake of the global financial crisis, policymakers have been exploring macro-prudential policies as a means of increasing resilience in bad times, and resisting the credit booms, though there is less optimism that such policies will achieve the latter.[24] The idea of resisting a credit boom is motivated in theory by distortions and accelerator effects in models(for example borrowers do not take account of the effect of their own borrowing on asset prices and others' collateral constraints).

In our model, there is no inefficiency associated with an expansion of credit. Indeed, resisting credit expansion introduces an inefficiency. The point here is to illustrate, in a general sense, the interaction between the stable funding requirement and credit expansion rather than making a normative assessment of such interaction. We illustrate this relationship by examining the responses to four shocks that are expansionary in terms of both GDP and credit. The shocks are an investment efficiency shock, a government spending shock, a fall in the world real interest rate and a compression of bank wholesale funding spreads.[25]

As shown in Figures 6a through 9b, in response to all four shocks, GDP rises and the household seeks to increase borrowing. In response to a rise in investment efficiency, the household wants to borrow to take advantage of the transitory increase in the productivity of investment by building up

[24] For example, see (Borio 2010)
[25] We do not consider a technology shock in our credit boom discussion because, while it expansionary for GDP, it is associated with a decline in debt and therefore credit.

the capital stock and so future income. An increase in government spending increases GDP directly, but with government spending financed through lump-sum taxes on households, it crowds out consumption and, particularly, investment. The household responds by borrowing (from non-residents) to smooth current consumption, avoid the costs associated with investment volatility and maintain the capital stock and so future income. A decline in the benchmark interest rate or a compression of wholesale funding spreads, encourages the household to borrow while funding is cheap. In response, the household runs up (net external) debt and increases investment to build up capital, and so future income.

In the following sections, we explain a general attenuating effect of the stable funding requirement on net credit expansion, and the amplifying effect of the stable funding requirement in response to bank funding cost shocks.

4.1 Attenuating effect

To finance higher household credit demand, the bank needs to increase funding. Short-term funding is always cheaper, but to avoid adjustment costs associated with a shortfall of stable funding, the bank needs to raise stable funding as well as short-term funding. In the benchmark model, the stable funding is raised mainly in the form of long-term wholesale funding. The increase in long term funding volumes drive up the marginal cost of long-term funding relative to short-term funding because long term markets are less liquid.[26] Higher long-term funding costs have a relatively small effect because long-term funding accounts for only about 10% of funding. Deposits are paid a markdown on the short-term rate (implicitly, they are a substitute for short term funding because the stable funding requirement does not bind),[27] so the rise in long term funding costs does not affect deposit rates directly. Deposits rise a little as the larger debt drives up the debt-sensitive risk premium and so short term funding costs and the retail deposit rate. Loans (bank assets) rise by more, depressing the retail funding ratio as shown in Figures 6b, 7b and 8b.

With a stable funding requirement, the rise in 5-year funding volumes drives up not only the cost of 5-year funding, but also the rate paid on retail deposits, since deposits are an explicit substitute for long-term funding (as a source of

[26] The cost of both long- and short-term funding rises with debt through the debt-sensitive risk premium that affects the benchmark long- and short-term rates.

[27] This is consistent with the general shift toward short term wholesale funding during periods of rapid credit growth.

stable funding).For the first three shocks, pass through of the higher long-term funding cost to deposits leads to an increase in deposits. Deposits rise by about as much as loans (so the retail funding ratio only moves a little). The deposit response allows a smaller rise in long-term funding volumes and so drives up spreads by less than in the benchmark model. The smaller rise in marginal long-term funding costs, however, is now passed through to the retail deposit base (about half of all funding) more of the funding base, driving up the average cost of funds and the retail lending rate. The bank allows the core funding ratio to decline a little to ease pressure on long-term funding costs. In response to higher retail loan and deposit rates, household net borrowing declines (loans are about the same, but deposits are higher), moderating the rise investment, capital and GDP.

As the stable funding requirement is increased, long-term funding accounts for an increasing share of funding (we hold the deposit share constant), so the rise in long-term funding costs affects a larger share of funding. However, a given nominal rise in credit demand drives up long term funding spreads by less in percentage terms (on a larger long-term funding base). On balance, these offsetting effects result in slightly more attenuation of net debt as the stable funding requirement is increased.

In our setup, gross lending is not attenuates, and in fact increases slightly, despite the fall in net borrowing. Therefore measured "credit growth" and the credit/GDP ratio are not attenuated. Net borrowing (net external debt) is gross loans less deposits. The fall in net debt could be achieved either by a fall in gross loans or a rise in deposits. The slightly larger expansion of gross loans here is driven by the rise in deposits. In a sense it is perverse for the household to deposit more only to borrow more. Deposits rise in part because the stable funding requirement increases the return on deposits as long-term (stable funding) funding costs rise, and in part because there is a utility value to increasing deposits. The rise in the return on deposits may be seen as efficient if it reflects the stability value of retail funding which, in the absence of the stable funding, is underpriced because of central bank liquidity insurance. If deposits were generated from a patient household as in (Gerali et al 2010) or if the deposit supply was less interest elastic, then deposits would rise by less, preventing the expansion in gross borrowing.

To summarise, in general, the presence of a stable funding requirement attenuates a credit expansion for two reasons. First, if funding spreads rise with volumes by more in less liquid long term markets, then by requiring that some of the credit expansion is funded from long term markets, the higher cost of funding slows credit expansion. If the 5-year market is liquid and there is little price response to rising volumes ($\kappa^M = 0$), then there is no attenuation. The calibrated value of κ^M of 17 implies that in response to a 1% rise in net new issuance of long-term debt, the bank faces an 80bp discount on its bonds. This is large, particularly for a credit boom scenario. The results here should be viewed as qualitative in nature in view of the uncertainty around the parameter κ^M, in particular, which determines the slope of the supply of 5-year funding in short run.

The second reason for attenuation is the change in basis for retail deposit rates from short-term to long-term wholesale funding costs as retail deposits become an explicit substitute form of stable funding. The run-up in marginal long-term funding costs is passed through to retail deposit rates. While the deposit response moderates the marginal increase long-term funding costs, it affects half of the bank's funding base. The change in basis for the retail deposit rate is the main difference between the black solid line and blue dashed line in Figures 6a and 6b. By driving up both deposit and lending rates, the rise in deposit rates encourages the household to increase saving and reduce borrowing.

4.2 Amplification of wholesale funding spreads

In contrast, the stable funding requirement amplifies the expansion of credit in response to a compression of wholesale funding spreads. The external wholesale funding spread shock affects both short- and long-term wholesale funding spreads, but the movement in the long-term funding spread, $m\tau_t$, is a multiple of short-term spread, τ_t (Figure 1) and the long term spread (which cannot be hedged) is carried for the duration of the funding. The response to a 25bp compression of the external 5-year funding spread is shown in Figures 9a and 9b.

In response to the shock, the household seeks to take advantage of compressed funding spreads by borrowing more to build up the capital stock, and so future income, while borrowing is relatively cheap. With lower debt service costs and higher expected future income, the household increases consumption and works less. The rise in net external debt drives up the risk premium and so the benchmark real interest rate.

To meet higher credit demand, the bank needs to raise funding. In the benchmark model, funding is mainly raised from wholesale markets. The bank prefers short-term funding which is always cheaper, but also raises long-term funding because of the stable funding requirement. Increasing funding in less liquid long-term markets drives up the cost of long-term funding. Deposits rise because the marginal utility of consumption is low (consumption is high), and because the fall in the retail lending rate reduces pressure to use internal funds. Deposits rise by less than the increase in loans so the retail funding ratio declines. The bank takes advantage of the transitory compression of funding spreads by increasing 5-year funding because the lower funding spread reduces long-term funding costs for the duration of the funding.

In the presence of a stable funding ratio, the lower cost of 5-year wholesale funding is passed through to the retail deposit rate. With cheap long-term wholesale funding there is little incentive to bid for deposits. As shown in Figure 9b deposits now fall, depressing the retail funding ratio by much more than in the benchmark model.

As the stable funding ratio is increased, the rollover of 5-year funding is higher, so the low funding spread feeds into a higher share of wholesale funding, depressing funding costs and in turn lending rates by more, increasing the incentive to borrow. At a higher stable funding ratio, a given rise in the bond issuance accounts for a smaller percentage change, pushing up funding costs by less so the marginal costs of core funding fall by more as the stable funding requirement increases. The larger decline in the deposit rate leads to a larger decline in deposits. The larger declines in the average cost of funds and the retail lending rate encourage the household to borrow more. The fall in deposits and the rise in loans translate into a larger rise in net external borrowing.

In contrast to the attenuation of credit expansion discussed in the previous section, the presence of a stable funding requirement amplifies the credit expansion in response to a compressed funding spread. The attenuating effect is still present, but is dominated by the fall in the long-term funding spread associated with the shock. For the three previous shocks, there was a significant improvement in the deposit response during credit expansions. Here, however, instead of a rise in deposits, deposits decline. The degree of amplification increases both in the level of the stable funding requirement (higher share of long-term funding, see Figure 2) and in the level of the net external debt (higher rollover generally). In the impulse response functions, we have not accounted for any steady-state decline in net external debt associated with the introduction of a stable funding ratio so may overstate the degree of amplification. Figure 10 suggests that the fall in the steady state debt would need to be very large to offset the amplification. Moreover, if spreads in 5-year funding markets respond only weakly to increases in funding volumes ($\kappa^M \to 0$), the rise in GDP and net external debt may be 50% greater than those shown. As long-term markets are likely to be relatively liquid when funding spreads are small (implicit in the shock), our calibration of κ^M is probably high and we may understate the degree of amplification.

In summary, the stable funding requirement attenuates credit expansion associated with all shocks in the model except the wholesale funding spread shock which is amplified. The net effect depends on the magnitude of liquidity effects (prices rise with volumes) in long-term markets and the nature of shocks driving credit expansion. When markets are liquid in a boom or "savings glut" scenario, a relatively flat supply of long-term funding favours the amplification story. However, the scope for amplification is bounded because the long term funding spread can only be compressed by about 50 basis points (from the the average spread of about 50bp pre-GFC to zero). Accounting for some fall in steady state net external debt associated with higher steady-state funding costs as the stable funding requirement is introduced and subsequently increased would further favour an attenuation story during a boom phase. On balance, these effects are likely to be small compared to the potentially adverse effects in the event of market stress discussed in the next section.

5 Outcomes during market stress

In this section, we consider the response to a sharp rise in the wholesale funding spread, indicative of market stress. Whereas the compressed funding spread was bounded, funding spreads in long-term markets can rise sharply during crises (Figure 1).

It is useful to think of two types of wholesale funding market stress: systemic and idiosyncratic. Here our focus is mainly the former - stress to funding costs that is unrelated to the state of the individual bank. As discussed in Acharya and Skeie (2011), liquidity hoarding can lead to very high spreads for even the most creditworthy borrowers. So lower ex-ante liquidity needs may have little affect on the probability of such an external event or the costs of funding in the face of such an event.

Funding market pressure related to an individual bank's balance sheet is more likely to involve issues of solvency, and imply endogenous feedback from the stability of the bank's funding to the probability of funding market pressure and the rise in wholesale funding spreads.[28] Here we do not account for endogenous benefits of more stable funding on the probability or cost of funding market stress. Nor do we account for potential endogenous changes in the risk characteristics of bank assets in response to the imposition of a regulatory requirement. While a stable funding requirement buys the bank time, on its own is not a panacea: over time funding comes due and debt must be repaid.

The response to a 100bp rise in the 5-year wholesale funding spread (Figures 11a and 11b) is essentailly an inverted and scaled version of the compressed funding spread discussed above. Aa before, the rise in the funding spread has a double effect in long term markets: long-term funding spreads are larger,[29] and cannot be hedged so must be paid for the duration of the funding. In response to higher retail deposit and loan rates, the household saves more and borrows less. As the stable funding ratio is introduced, the cost effects pass through to retail rates and affect a growing share of long-term wholesale funding as the stable funding requirement is increased. The larger rise in retail rates increases the degree of deleveraging in response to the funding spread shock. The degree of deleveraging translates proportionately into falls in consumption, investment, capital, output and net external debt.

The immediate response of the bank is to sharply reduce long-term funding which is very expensive. Absent the benign effect of falling volumes on 5-year funding costs, the profit-maximising model bank would in fact shift into negative new issuance (sell assets and lend the proceeds of existing funding to the long-term market at the elevated rate. Here the beneficial liquidity effect is calibrated (κ^M) to avoid such an outcome.). The adjustment costs (terms in κ^M) moderate the fall in long-term funding by moderating the rise in funding costs.

To avoid the transitory high cost of long-term wholesale funding, the bank is willing to pay a lot for a one-period retail deposit. The full pass-through of the marginal cost of core funding to the deposit rate encourages the household to deleverage. The CFR falls by 1.2 percentage points (by construction to exhaust the banks' assumed 5 percentage point buffer in response to a GFC-sized (350bp) funding spread shock).

As the share of core funding rises, the shock affects a larger share of bank funding (higher 5-year rollover), leading to larger effects. Because the household

[28] See Aikman et al (2009) for a study of funding liquidity risk in a bank network model.

[29] In part this is because central bank liquidity operations ease liquidity pressures in short-term markets, and in part because the effects of precautionary liquidity affect long-term markets disproportionately (Acharya and Skeie (2011)).

is a net debtor, the rise in the loan rate affects debt service costs more than a rise in the deposit rate increases deposit interest income. In the absence of adjustment costs in term debt markets ($\kappa^M = 0$), funding costs do not fall with volumes and the effects are about 50% larger. The adverse effect of the shock is increasing in net external debt.

In principle, the higher retail deposit and loan rates should lead to a decline in the steady-state net external debt. In the calibration, we have not accounted for such a decline with the introduction or subsequent rise in the stable funding requirement. This not the right type of model (the steady state net external debt and risk premium parameters are fixed) to inform on the evolution of the net external position. Figure 10) shows the effects of the steady-state net external debt on the depth of the recession in response to the funding spread shock. The shift from the benchmark model to a CFR of 65% would need to be offset by a large fall in net external debt to get back to the original recessionary effect of the funding spread shock. The rise in costs is offset by a fall in the debt-sensitive risk premium. Each subsequent rise in the core funding ratio, however, would require a considerable further fall in net debt (about 30% of GDP) which is more than that implied by the rise in funding costs. Overall, the required fall in debt to offset the amplifying effects is implausibly large. Moreover, if many countries implement a stable funding requirement, the outcome may be low world real interest rates rather than shifts in external imbalances which must sum to zero globally.

How might a buffer stock of stable funding held by the bank above the regulatory requirement, or regulatory forbearance mitigate adverse outcomes in the face of elevated funding spreads?

5.1 Ex-ante buffers

Figures 12a and 12b, show the responses to a 100bp rise in the 5-year wholesale funding spread for a required CFR of 75% and buffers of 1%, 5% and 10% above the required level. The initial core funding ratios are calibrated at 76%, 80% and 85% respectively and the adjustment costs on core funding are calibrated to allow the observed CFR to fall to the same 75% minimum in all three cases in the event of a 350bp shock (3.5 times that shown). In the case of the 1% buffer, there is little scope to reduce 5-year issuance in response to the higher spread. With a 10% buffer, the bank can reduce 5-year issuance, avoiding the worst of the transitory funding shock, moderating macroeconomic effects.

So ex-ante buffers play a useful role, enabling the bank to weather a relatively short period of market stress and moderating the degree of deleveraging driven by higher funding costs. Overall, however, the macroeconomic effects of the buffers are modest: outcomes are still considerably worse than the benchmark model. Eventually, the bank finds itself at the minimum requirement and the associated cost structure.

5.2 Ex-post forbearance

In the face of a longer period of funding market stress, the buffer may be run down, leaving little scope to avoid higher funding costs. In the extreme case of long-term market closure (long-term markets become stressed earlier, by more and for longer), the bank has little scope for substituting to short-term funding without breaching the regulatory requirement. In contrast, if instead of a balance sheet requirement, more stable funding were achieved through a tax on non-core funding, there would be scope for the bank to substitute toward cheaper short-term funding in periods of stress.[30] Here we consider a combination of the two, in the form of a price-based forbearance policy to mitigate the effects of the requirement in extreme states.

In normal times, central banks typically provide short-term collateralised loans in daily operations. Such lending is generally available at a small penalty[31] over the benchmark rate. If such funding can be counted as core funding, its availability would undermine the incentives for the bank to raise stable funding if long-term wholesale funding spreads are even a little bit elevated. In the event of a funding spread shock, an additional 100 basis point spread carried for five years is very expensive compared to 25-50 basis points on 1-quarter funding.

In the event of severe market stress however, it may be sensible for a regulator to consider some form of forbearance to avoid the adverse effects of high external funding spreads on the economy (deleveraging and recession). What might such forbearance look like? One option is a separate central bank facility with a higher penalty rate than normal liquidity operations that can

[30] A tax-based approach might be more difficult than a balance sheet requirement to implement in normal times, potentially being a complicated graduated tax, subject to time-varying incentives.

[31] In New Zealand, 50 basis points over the policy rate equivalent to about 25 basis over the interbank benchmark rate.

be counted toward the stable funding requirement.[32] Such a facility could be priced to come into play automatically, serving as a sort of release valve when the external funding spread is large, but fall into disuse when funding spreads decline.

Figure 13a and 13b shows the effects of such a facility. The black line, as before, shows the benchmark model and the broken green line the outcome for a CFR of 75% plus 5% buffer. Ex-post forbearance has a greater moderating effect on GDP than the 10% ex-ante buffer discussed above. The larger effect is essentially because the core funding ratio can fall below the ex-ante requirement, substituting towards cheaper short term funding by more. This is true even if the facility is offered at a penalty of 200bp (in the face of a 100bp funding spread shock). While 200bp may sound like a steep penalty rate in the face of a 100bp funding spread shock, the bank still substitutes to the central bank facility. Again, this is because funding market stress is a sort of "double whammy" for long-term markets: not only are long-term spreads relatively high, but they must be carried for the duration of the funding. A high penalty rate would usefully discourage use of a core funding facility in normal times, and allow it to fall into disuse as funding spreads ease in the aftermath of a funding spread shock. The point here is not to recommend what the specific penalty rate should be, but to illustrate the potential of such a facility. Of course, there are important issues around moral hazard that need to be considered in policy design.

In practice, during periods of market stress, banks tend to *increase* the share of stable funding through a combination of weak loan growth and a rise in stable funding. The observed increase in the stable funding ratio during periods of stress may be driven by market pressures and by fear of negative signalling effects. The observed decline brings into question the potential effectiveness of both buffers and forbearance.

The term of a core funding facility may affect signalling effects. Here the facility is based on 90-day loans for tractability. It could, instead be based on loans with a maturity greater than a year, consistent with the regulatory

[32] Central bank liquidity operations mitigate bank vulnerabilities and can be considerable (as they were in the recent crisis). There is, however, a limit to their effectiveness. The scope for banks to shift to central bank liquidity provision is limited by the quality of their collateral (subject to escalating haircuts). During the crisis, banks quickly ran out of repo-eligible collateral, leading central banks to expand the range of assets accepted, but eventually such expansion implies a shift of bank credit risk to the fiscal accounts. Moreover, if the availability of central bank liquidity operations leads banks to take on greater refinancing risk (moral hazard), then the scope for liquidity operations to mitigate shocks becomes diminished.

definition of stable funding. A longer-term facility would be less likely to be associated with negative signalling effects. Second, the preannounced nature of such a facility may moderate negative signalling effects Lucas and Stokey (2011) argue that:

> "*During a liquidity crisis the [central bank] should act as a lender of last resort*" ... The central bank "*should announce its policy for liquidity crises, explaining how and under what circumstances it will come into play. There is no gain from allowing uncertainty ...The beliefs of depositors/lenders are critical in determining the contagion effects of runs that do occur.*'

5.3 A counter-cyclical overlay?

The adverse outcomes in periods of funding market stress suggest that a counter-cyclical overlay may be useful for the same reasons that motivate a counter-cyclical capital buffer. In particular, buffers are only useful if they can be used, and balance sheet requirements may be amplifying if maintaining the requirement in times of stress is very costly.

Our discussion of policy forbearance above can be thought of in terms of such an overlay. One could think of the level of a stable funding requirement as micro-prudential in nature (as are capital requirements), but with a counter-cyclical macro-prudential overlay. The natural indicator variable for the counter-cyclical buffer would be long term funding costs. In periods of very easy funding and compressed long-term funding spreads, the counter-cyclical buffer would require banks to build up a buffer of long term funding (which could be done by increasing the share of long-term funding or lengthening the maturity of a given share of long-term funding) when long term funding is cheap. Conversely, when long-term funding markets become stresses and spreads are high the buffer would be released. We leave formal analysis of a counter-cyclical buffer for further work in a model with active monetary policy since monetary policy provides an alternative means of mitigating adverse effects of funding cost shocks (by reducing the benchmark rate).

6 Sensitivity

In this section we briefly consider variations in parameters values. For space considerations, only the macroeconomic variable responses to selected shocks are shown.

A potentially important factor in the dynamics discussed here is the interest rate elasticity of deposits, the inverse of γ^D. Figure 14 shows the response to a funding spread shock for values of $\gamma^D = 1, 3(\text{baseline})and10$. As deposits become less elastic (higher γ^D), the scope to avoid the worst of the funding spread shock by bidding for deposits is reduced. As a result, the bank reduces 5-year funding by less, the average cost of funding rises by more and the extent of deleveraging and recession is greater.

Next we consider the effects of additional smoothing to consumption. This is introduced in the form of habit in consumption: consumption utility takes the form $log(C_t - hC_{t-1})$. In the baseline model, the consumption habit parameter is implicitly zero, and here we consider a value of 0.8. As shown in Figure 15 (solid grey line) this has very little effect on the outcomes.

Reducing the labour supply elasticity (inverse of ζ) reduces the labour supply response to funding spread shocks (broken blue lines in Figure 15). It moderates the initial effects of swings in labour supply on GDP, but has little effect on medium-term macroeconomic outcomes.

In our baseline result, bank funding costs are fully passed through to retail interest rates. If banks absorb part of changes to funding costs in their profit margins, the economic effects may be muted as the bank is assumed to be foreign-owned. To examine this scenario, we use the setup for monopolistic competition in retail banking set out in Gerali et al (2010) (see Appendix B). The calibration of the steady-state markup on the loan rate and markdown on the retail deposit rate are based on observed New Zealand bank spreads. The calibration of the stickiness parameters is based on estimates for European banks in Gerali et al (2010). As shown in figure 16, stickiness in retail rates is introduced on loan and deposit rates separately and in combination. The values are based on those estimated for the euro area by . Stickiness in the retail lending rate moderates outcomes a little, reducing the extent of deleveraging, at the cost of lower bank profits.

Finally, we consider setting the adjustment cost parameter κ^M that determines the slope of the 5-year funding supply curve (in the short run) to zero. κ^M is an important parameter in considering the scope for resisting a credit boom. With $\kappa^M = 0$, there is no attenuation of the investment efficiency, fiscal and world real interest rate shocks relative to the benchmark (Figure 17 shows the responses to an investment efficiency shock). The adjustment cost was the only model feature capable of resisting the boom. Any steady-state fall in net external debt (not accounted for here) would still provide attenuation.

Figure 18 shows the response to a compression of the funding spread for $\kappa^M = 0$. In this case, the degree of amplification of the shock increases. The reason is that the adjustment costs provide cost relief as rates fall with volumes in less liquid markets. Without such relief, the outcomes are more severe.

7 Conclusions

This paper introduced a profit-maximising bank with disaggregated liabilities, including a tractable setup for long-term funding without benchmark interest rate risk and used this setup to explore the macroeconomic effects of a stable funding requirement in an open economy, general equilibrium model. A stable funding requirement, designed to reduce banks' rollover risk, is found have important effects on on bank funding costs and, in turn, on retail deposit and loan rates and the economy.

In general, the presence of a stable funding requirement attenuates credit expansion. In steady-state, higher funding costs associated with more long-term funding and higher retail deposit rates imply a lower steady-state net external debt. In terms of dynamics, as funding costs rise with volumes by more in less-liquid long-term funding markets, (ii) those rising costs drive up the rate paid on retail deposits and (iii) the higher share of stable funding (long-term funding and retail deposits) implies higher exposure to those rising costs.

Higher exposure to long-term markets, however, may increase the procyclicality of fluctuations in funding spreads, amplifying the effects of compressed spreads in a boom and elevated spreads in times of stress. These spreads matter a lot for the average cost of funds because long-term spreads are larger than short-term spreads and must be paid for multiple periods. In the presence of a stable funding requirement, greater exposure to long-term markets can lead to more adverse macroeconomic outcomes in the event of elevated spreads (market stress). Policy experiments showed that adverse effects can be moderated through suitable policy design, and suggest that counter-cyclical policy may play a useful role.

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Table 1
Model calibration

	Parameter	Benchmark
Basic RBC		
α	capital share	0.33
δ	depreciation rate	0.025
ζ	inv. elasticity of labour supply	1
h	consumption habit	0
ϱ	debt-sensitive interest premium parameter	0.0018
υ	investment adjustment cost parameter	0.07
G/Y	steady state government spending/GDP	0.18
B^e/Y	steady state external debt/GDP	0.80
β	discount rate	0.990
D/Y	steady state retail deposits/GDP	2.8
Deposits		
γ^D		3
Bank		
ν^{cfr}	desired core funding ratio	0.58 (65% no buffer)
κ^{cfr}	CFR adjustment cost parameter	0.2
κ^M	5-year funding adjustment cost parameter	17
m	duration of multi-period funding (quarters)	17
tp	Term premium (mean value of funding spread)	0.00012
ϵ^D	interest elasticity of deposit supply	10
κ^D	stickiness of retail deposit rates	0
ϵ^L	interest elasticity of loan demand	4
κ^L	stickiness of retail loan rates	0
Shock AR1 coefficients		
ρ^A	Productivity	0.8
ρ^I	Investment efficiency	0.8
ρ^G	Government spending	0.8
ρ^{i*}	Foreign interest rate	0.8
ρ^τ	Funding spread	0.875
ρ^{cfr}	CFR increase	0.9999
ρ^D	Deposit competition	0.8

Table 2
Moments of the model

	New Zealand data a/				Benchmark model b/			
	St. Dev	Relative St. Dev.	AR1 Coeff.	Correl. with y	St. Dev	Relative St. Dev.	AR1 Coeff.	Correl. with y
y	1.31	1.00	0.84	1.00	2.47	1.00	0.83	1
c	1.26	0.97	0.81	0.67	1.25	0.51	0.98	0.589
x	6.02	4.60	0.73	0.82	8.17	3.31	0.9	0.82
n	0.76	0.58	0.28	0.31	1.00	0.40	0.83	0.86
r90	0.00	0.00	0.85	0.50	0.03	0.01	0.95	-0.55

a/ For period 1995Q1 to 2007Q2
b/ Based only on technology shocks.

Table 3
CFR, NSFR and model calibration

Observed CFR	estimated NSFR	ν^{cfr}	duration (m)	deposit (% of loans)	long-term wholesale (% of loans)	short-term wholesale (% of loans)
65%	74.0%	58.1	17	0.47	0.11	0.42
70%	80.5%	63.7	17	0.47	0.17	0.36
80%	93.5%	74.8	17	0.47	0.28	0.25
90%	106.5%	86.2	17	0.47	0.45	0.08

[a] NSFR and CFR calculations are different in the details. It is roughly estimated that a net stable funding ratio of the type proposed under Basel III would be equivalent to a core funding ratio of about 90%, although this figure is uncertain.
In all cases steady-state deposits are assumed to remain at 47% of total funding.

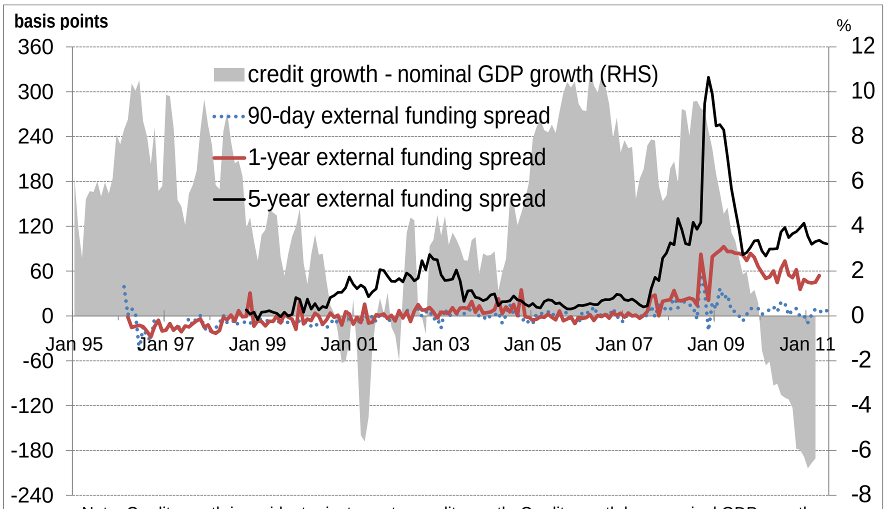
Table 4
Steady state values

	Parameter	Benchmark Model	65%CFR +5% buffer
C/Y	consumption/GDP	0.550	0.553
I/Y	investment/GDP	0.211	0.209
G/Y	Government spending/GDP	0.18	0.18
NX/Y	net exports/GDP	0.058	0.059
K/Y	capital/annual GDP	2.11	2.09
B^e/Y	Net external debt/annual GDP	0.8	0.8
B^S/L	one-period wholesale funding / Loans	0.42	0.36
$\tilde{B}^M/L$	5-year wholesale funding / Loans	0.11	0.17
D/L	Retail Deposits / Loans	0.47	0.47
CFR	Stable funding / Loans	65%	70%
r	benchmark interest rate (annual)	4.0%	4.0%
r^L	retail loan rate (annual)	5.6%	5.8%
r^b	average funding cost (annual)	4.2%	4.4%
r^a	average cost of core funds (annual)	3.9%	4.2%
r^c	marginal core funding (annual)	4.6%	4.6%
r^D	retail deposit rate (annual)	3.7%	4.1%

Table 5
Asset and Liability weights for CFR, NSFR and model

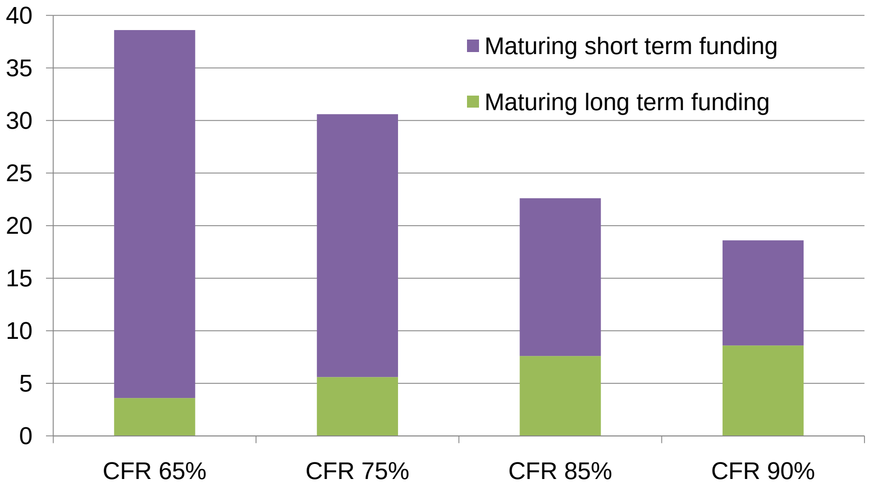
	Model	**CFR**	**NSFR**
Liabilities			
Short-term wholesale	0%	0%	0-50%
Retail			
less than one year	100%	20-90%	80-90%
		(mostly 90%)	80-90%
greater than one year	100%	100%	100%
Long-term wholesale			
Residual maturity < 6months	100%	0%	0-50%
Residual maturity 6-12 months	100%	50%	0-50%
Residual maturity > 12 months	100%	100%	100%
Capital	N/A	100%	100%
Assets			
Securities and liquid assets	N/A	N/A	0-50%
Loans and advances	100%	100%	65-100%

Figure 1
Credit cycles and external wholesale funding costs



Note: Credit growth is resident private sector credit growth. Credit growth less nominal GDP growth provides a measure of "excess" credit growth. Funding spreads are indicative USD borrowing costs hedged to NZD using an FX swap or cross currency swap. Spread to bank bill or bank bill swap.

Figure 2
Funding required after one year in the event of market closure (% of loans)



Assuming deposits are 47% of loans, short term wholesale funding is 90-day and long-term wholesale funding is 5-year.

Figure 3
Bank structure

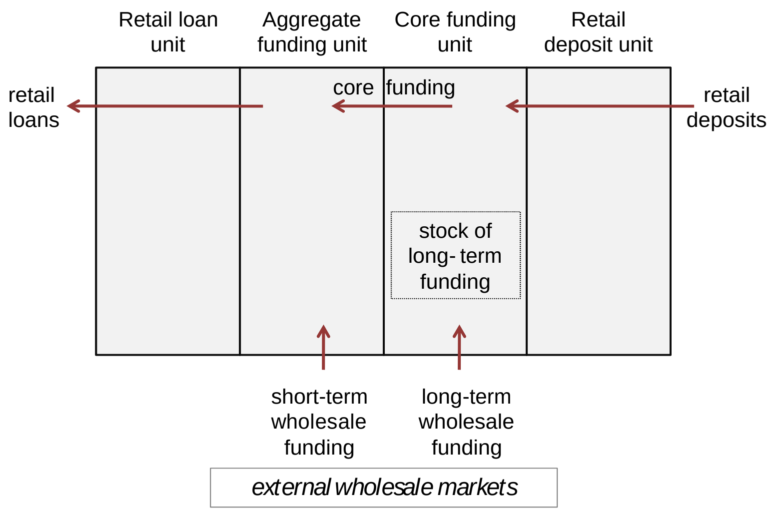


Figure 4
Sources of New Zealand bank funding

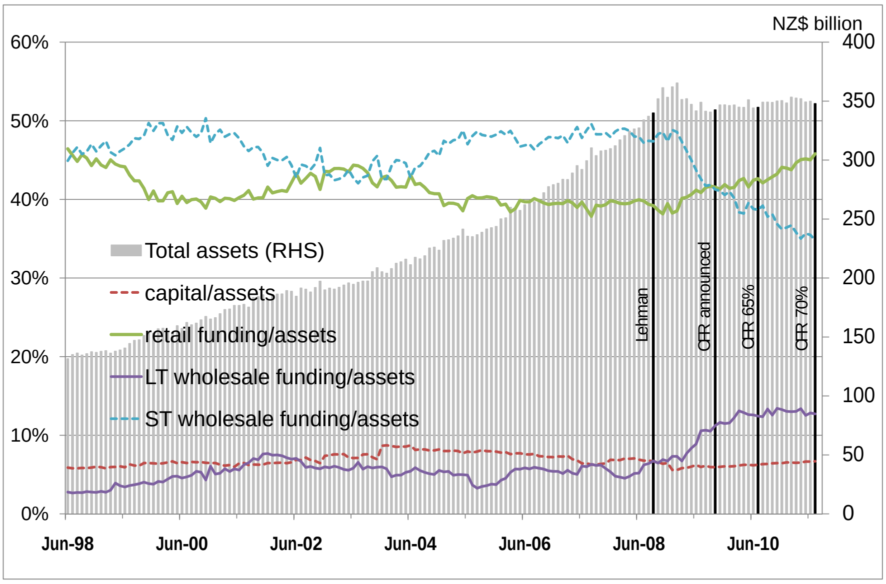


Figure 5
Bank interest rate spreads to swap

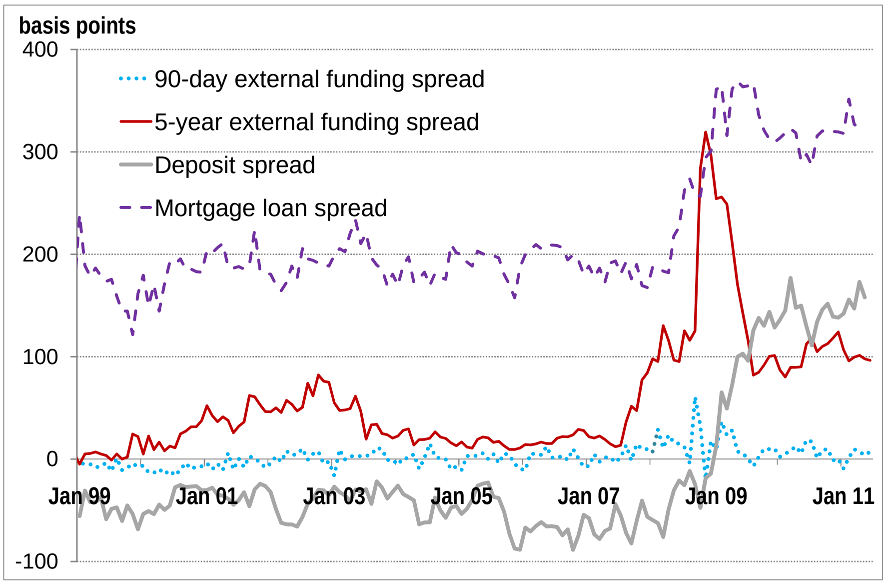
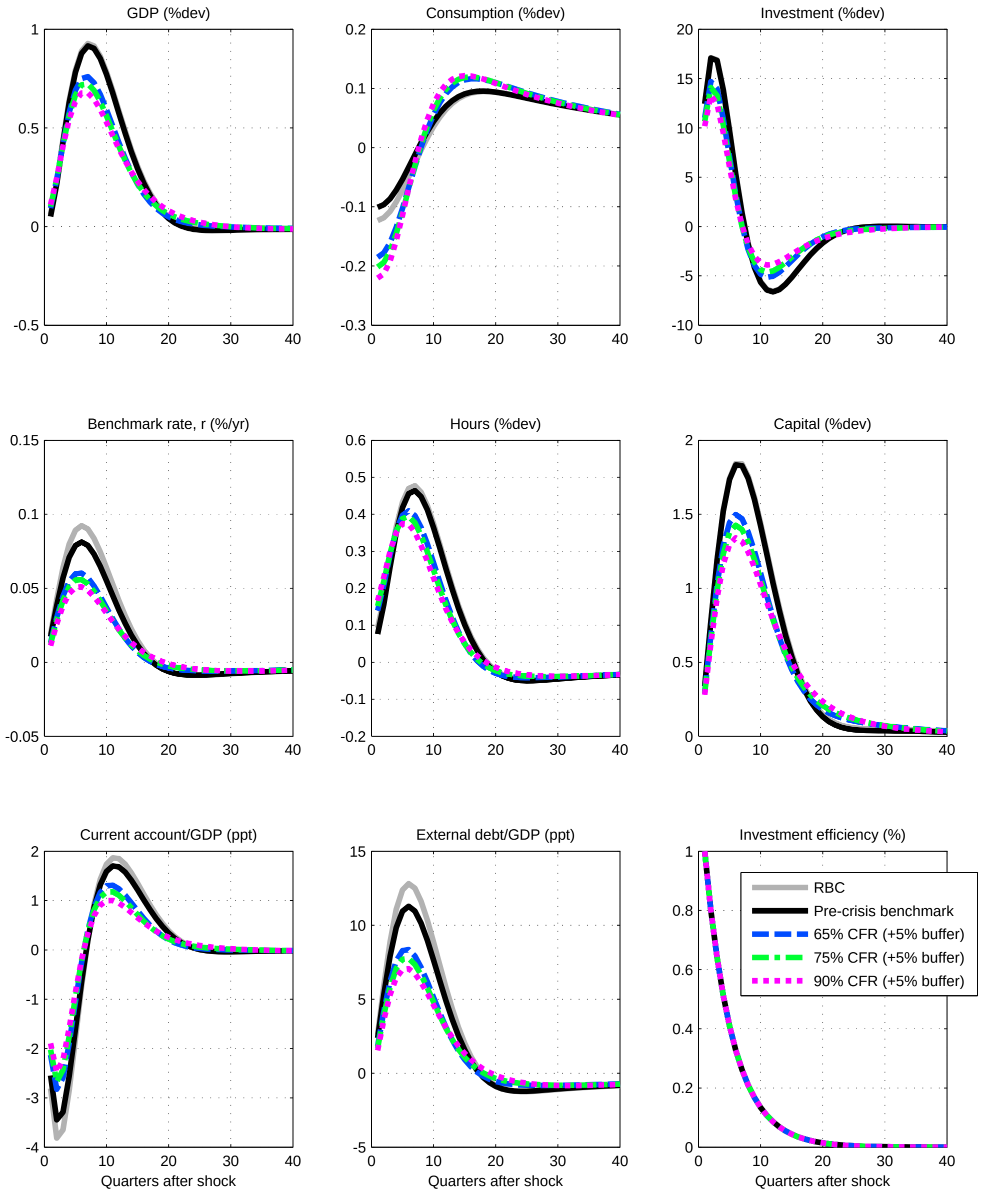
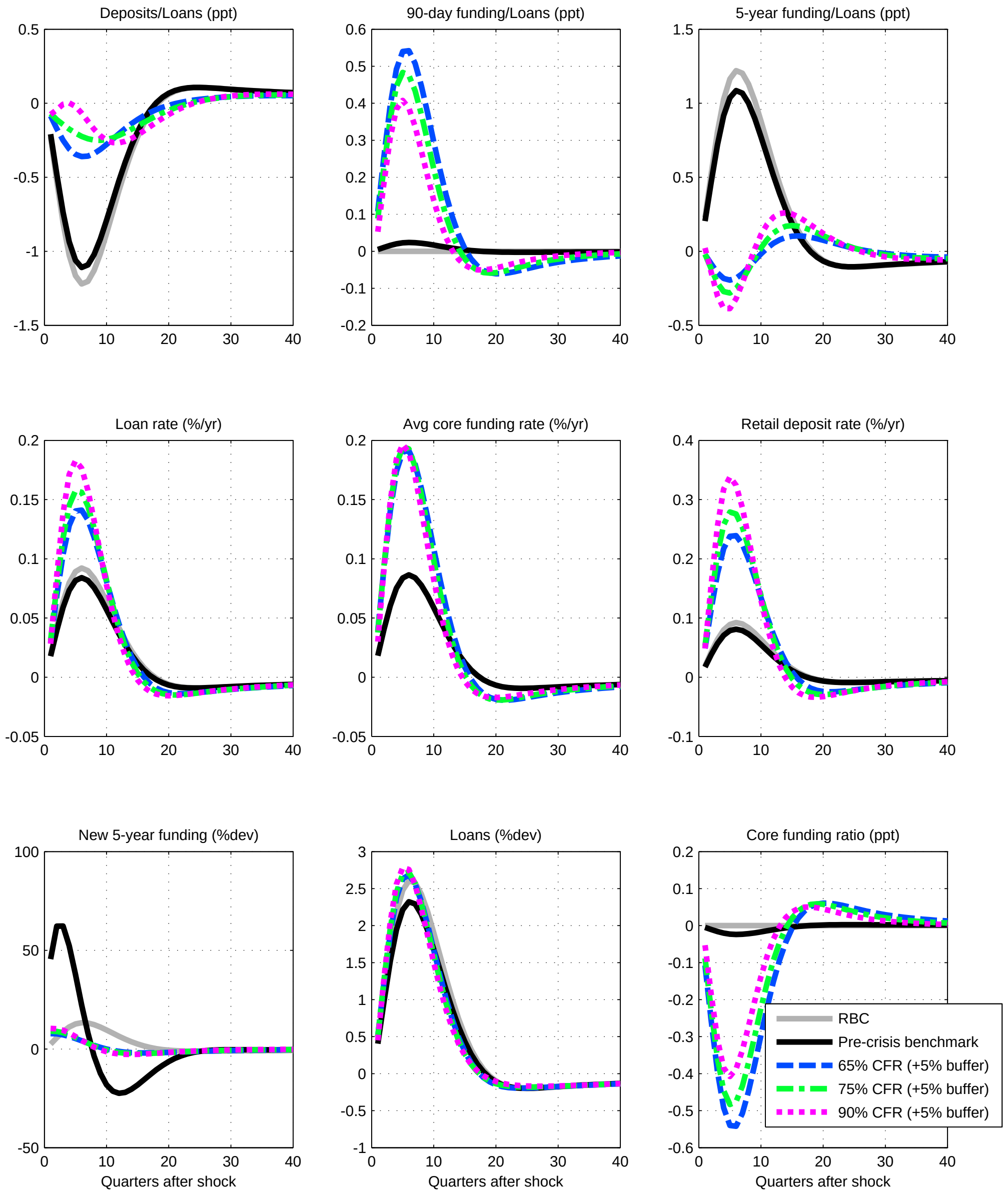


Figure 6a
IRF: 1% Investment efficiency shock, economic variables



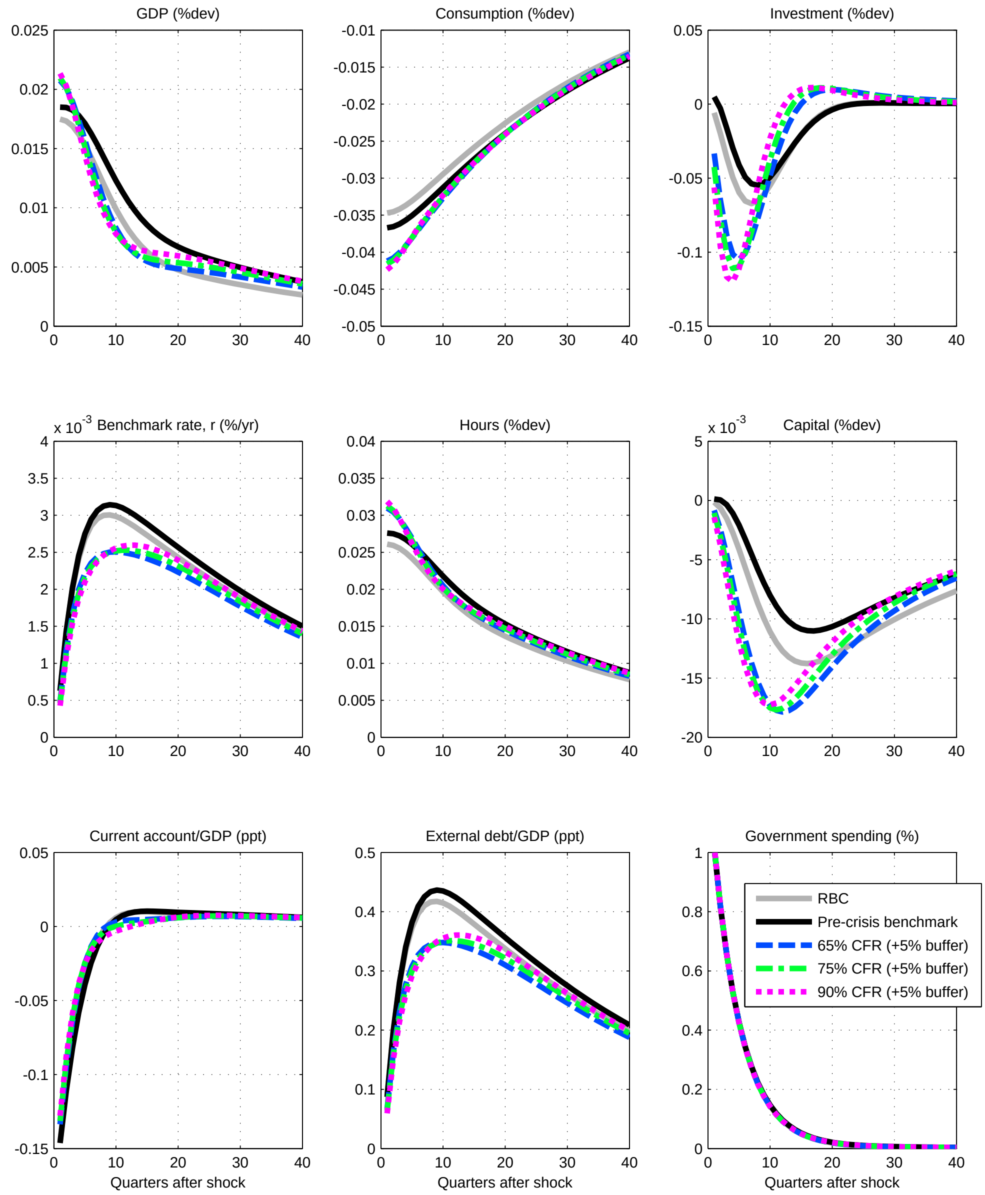
Note: Variables are % deviation from steady state except (i) NX/GDP, CA/GDP and net external debt/GDP which are percentage point deviation from steady state ratios and (ii) the benchmark interest rate which is percentage point deviation from the steady state level.

Figure 6b
IRF: 1% Investment efficiency shock, bank variables



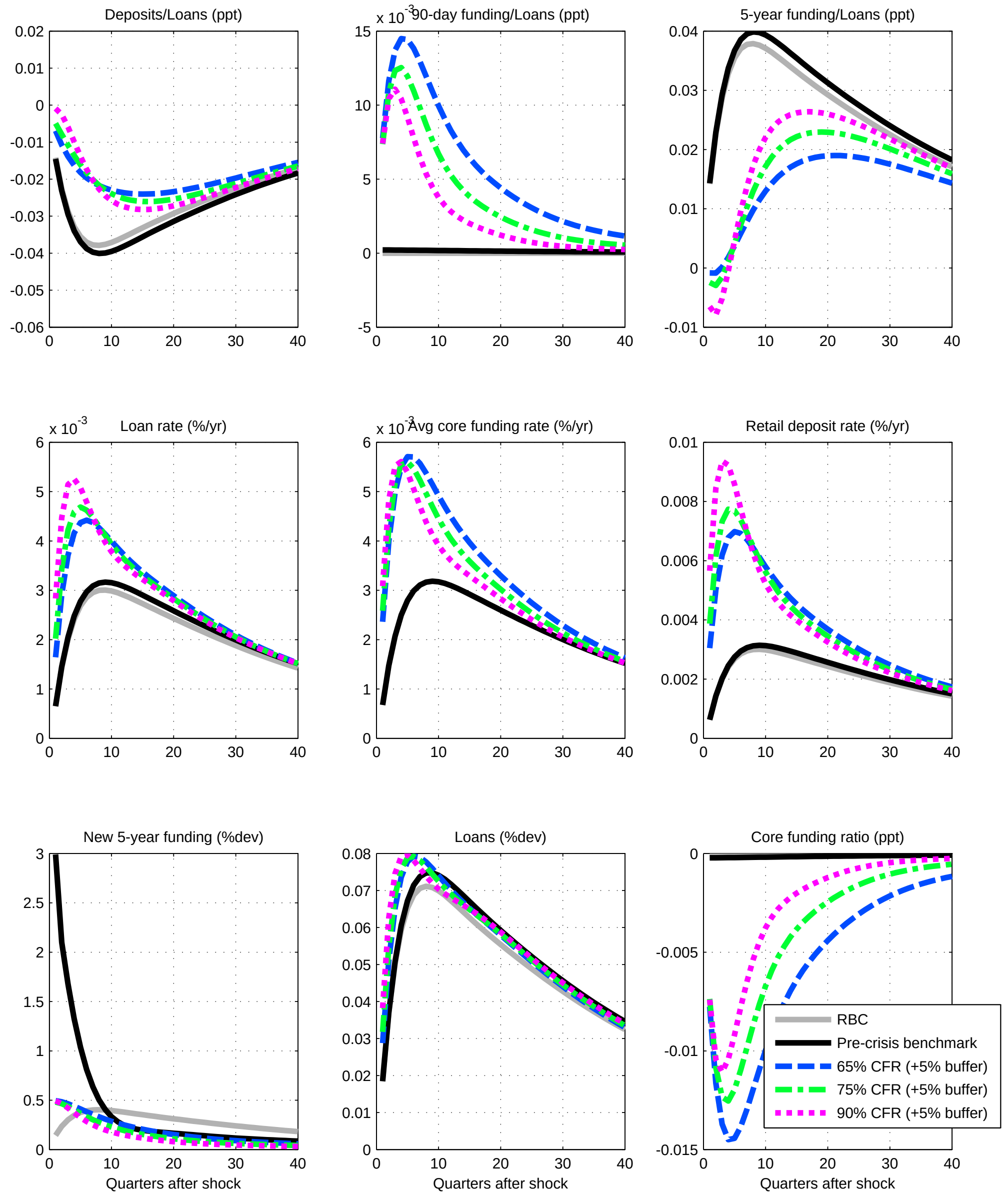
Note: Variables are percentage point deviation from steady state, except new 5-year funding B_t^M and loans which are % deviation from steady state.

Figure 7a
IRF: Fiscal shock (1% of GDP), economic variables



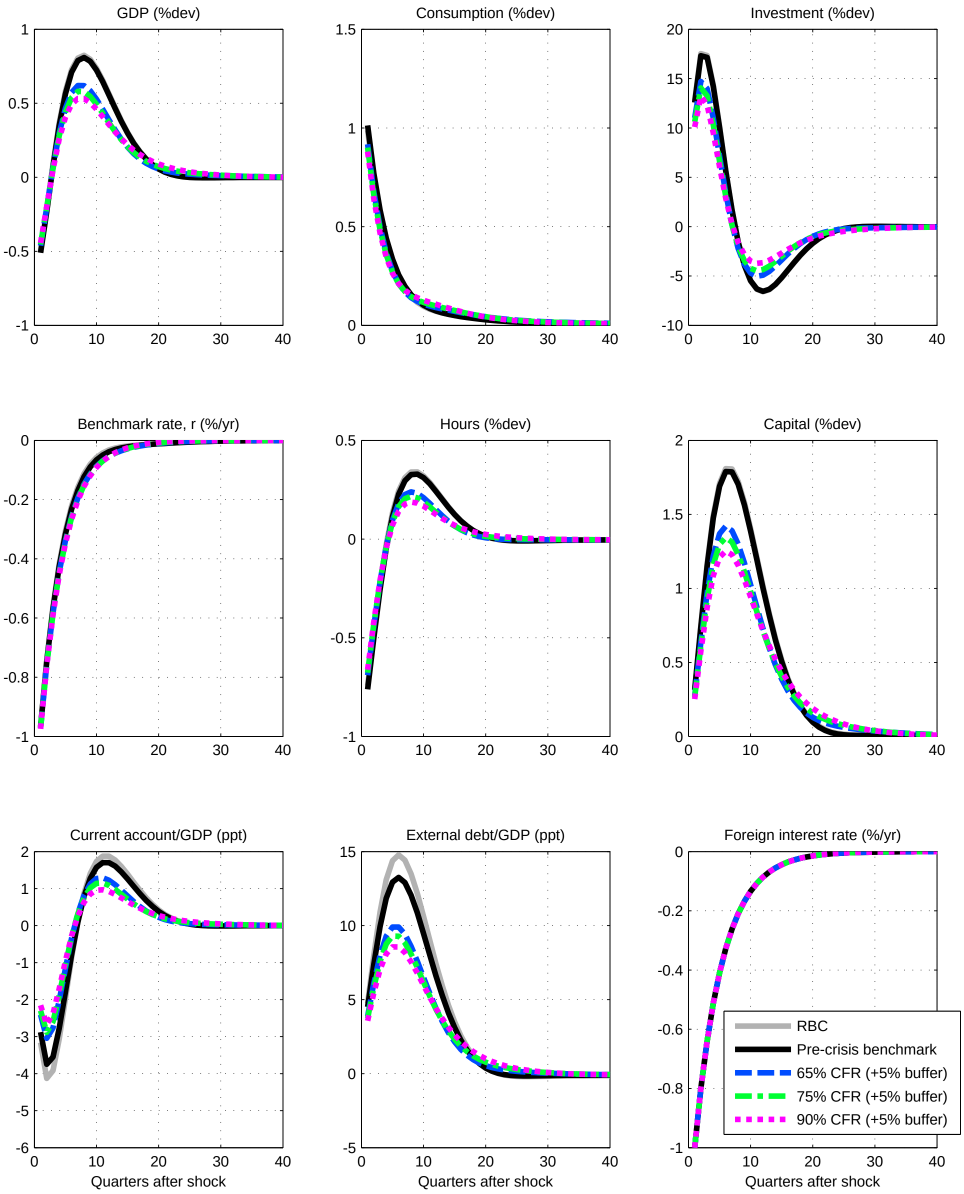
Notes: See footnote to Figure 6a

Figure 7b
IRF: Fiscal shock (1% of GDP), bank variables



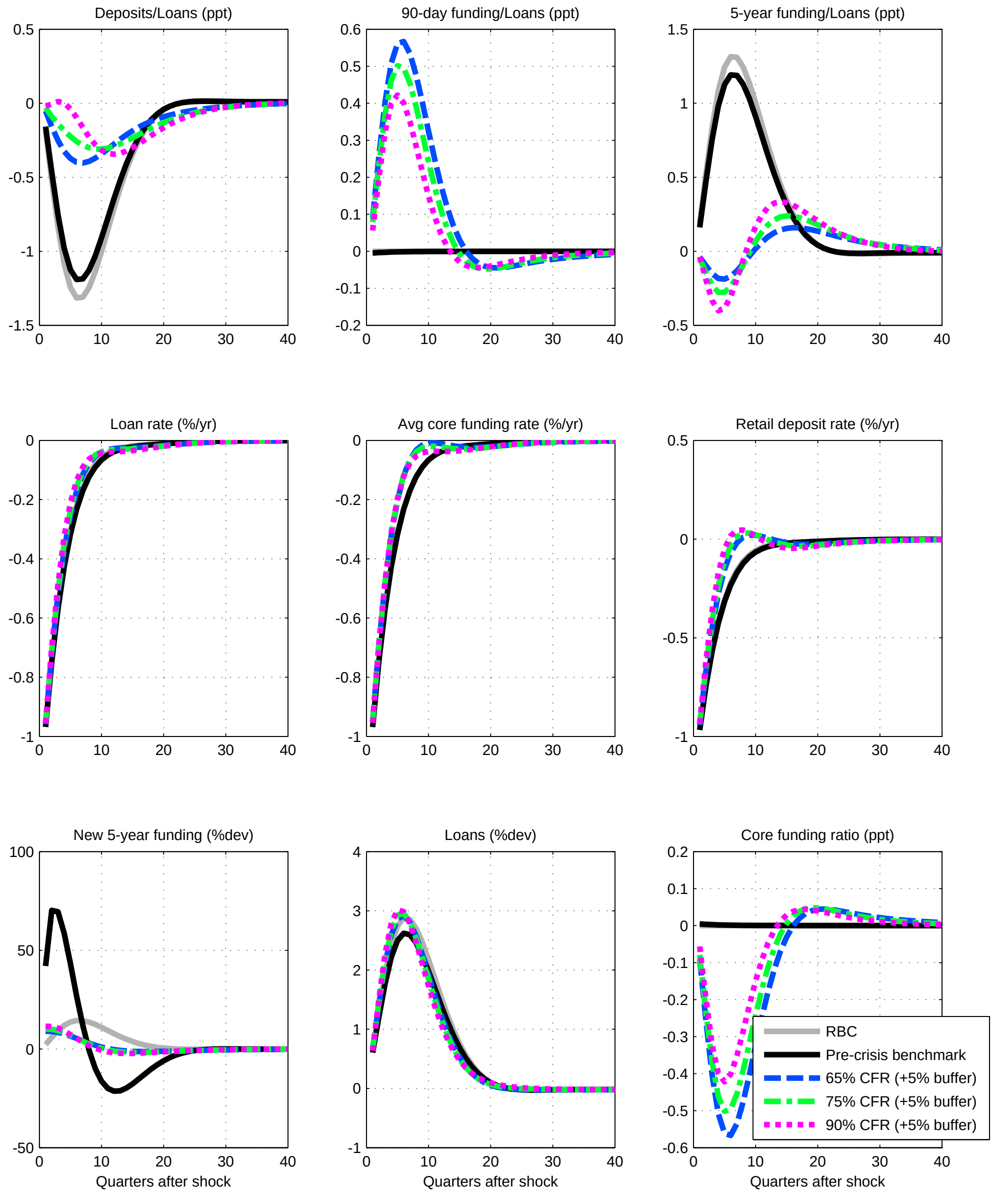
Note: See footnote to Figure 6b

Figure 8a
IRF: 100bp fall in foreign interest rate, economic variables



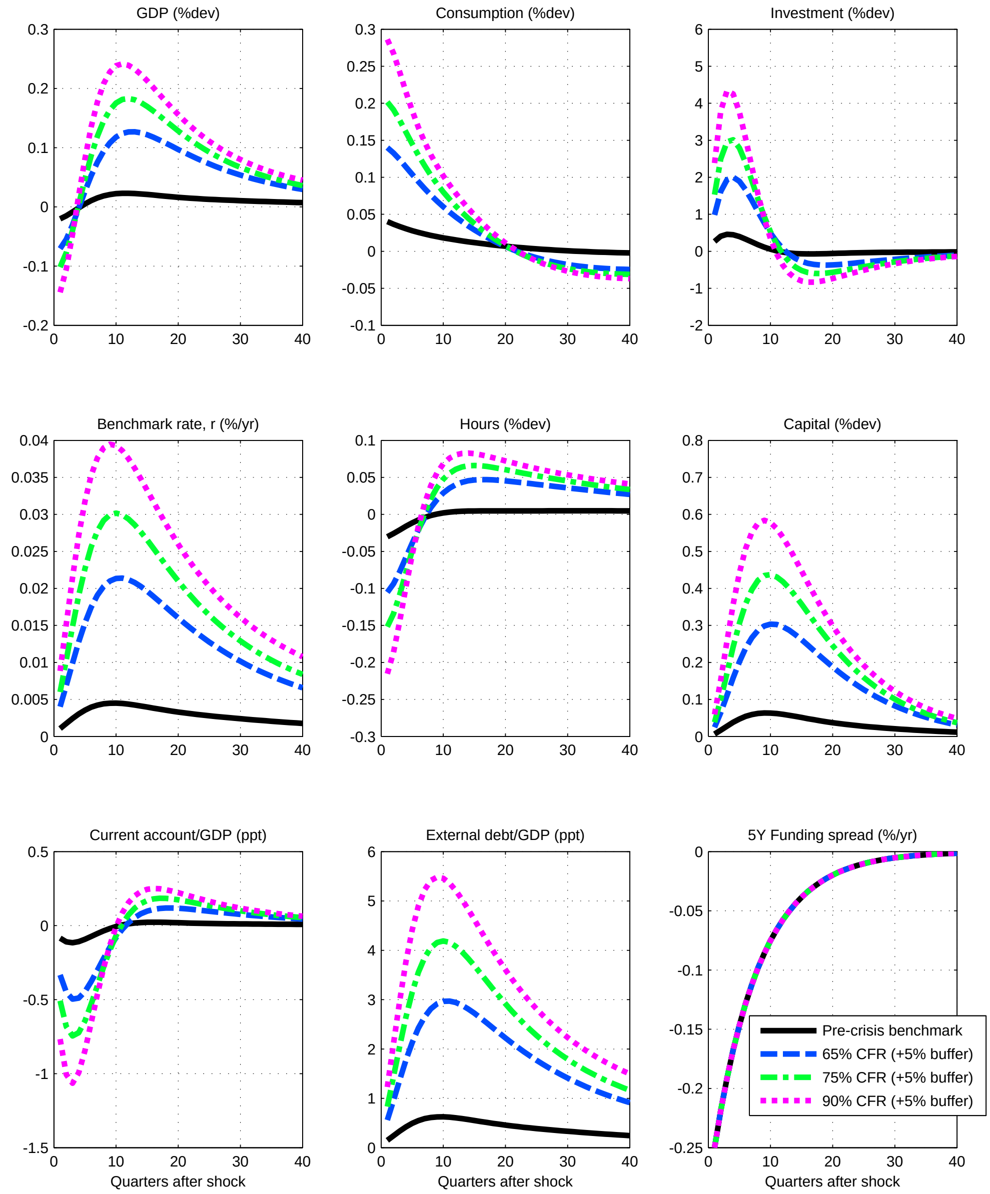
Notes: See footnote to Figure 6a

Figure 8b
IRF: 100bp fall in foreign interest rate, bank variables



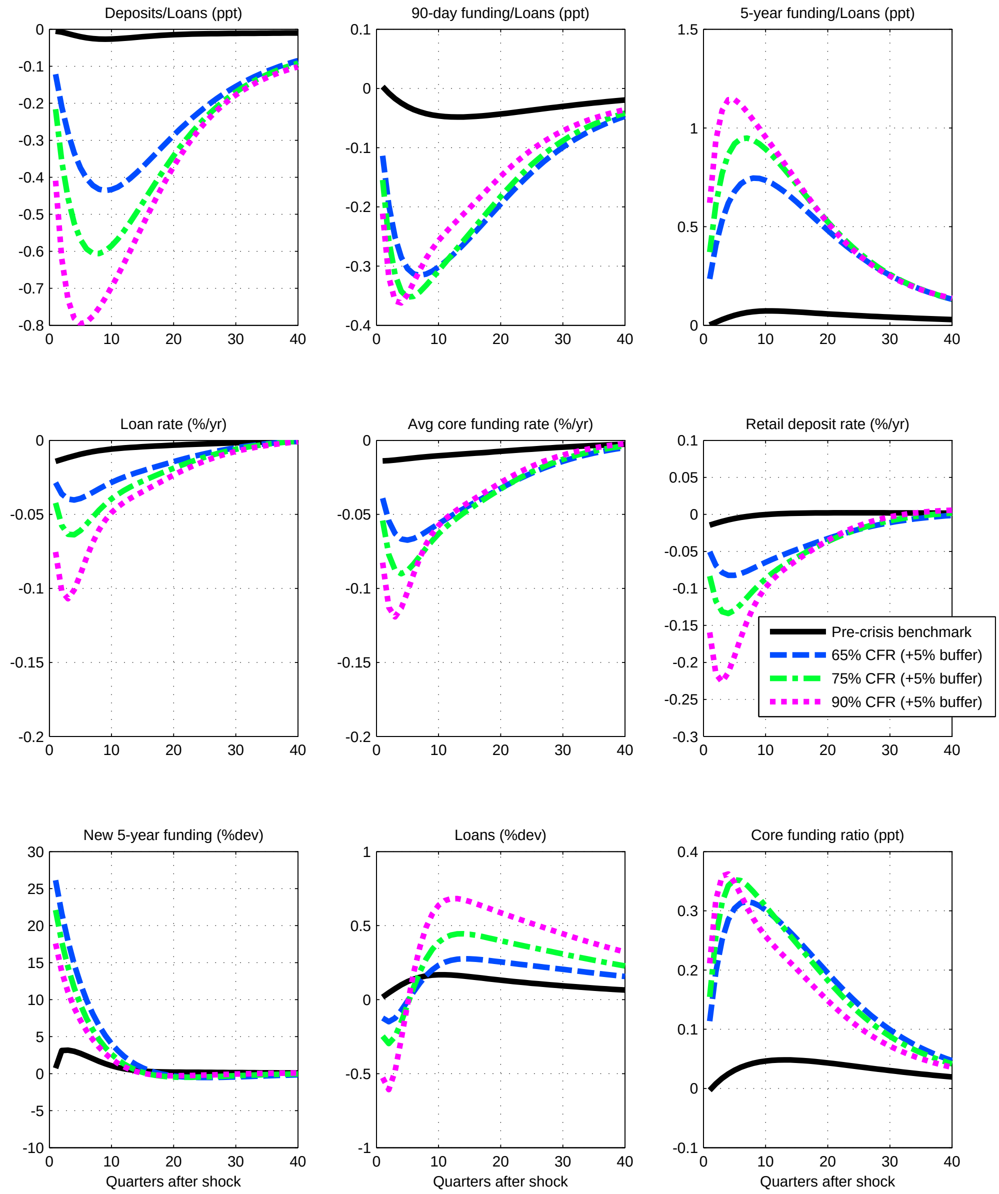
Note: See footnote to Figure 6b

Figure 9a
IRF: 25bp compression of funding spread, economic variables



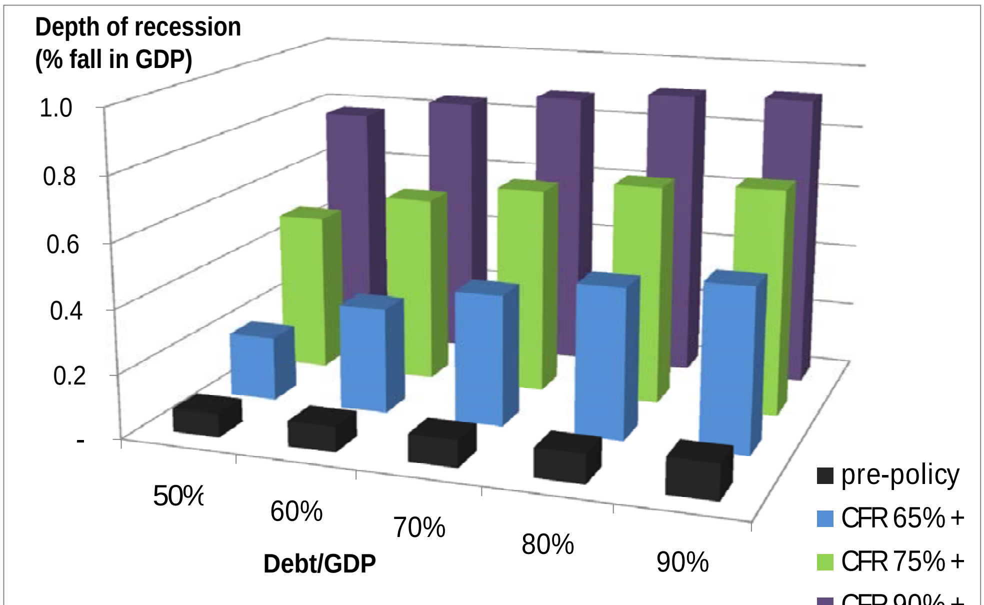
Notes: See footnote to Figure 6a

Figure 9b
IRF: 25bp compression of funding spread, bank variables



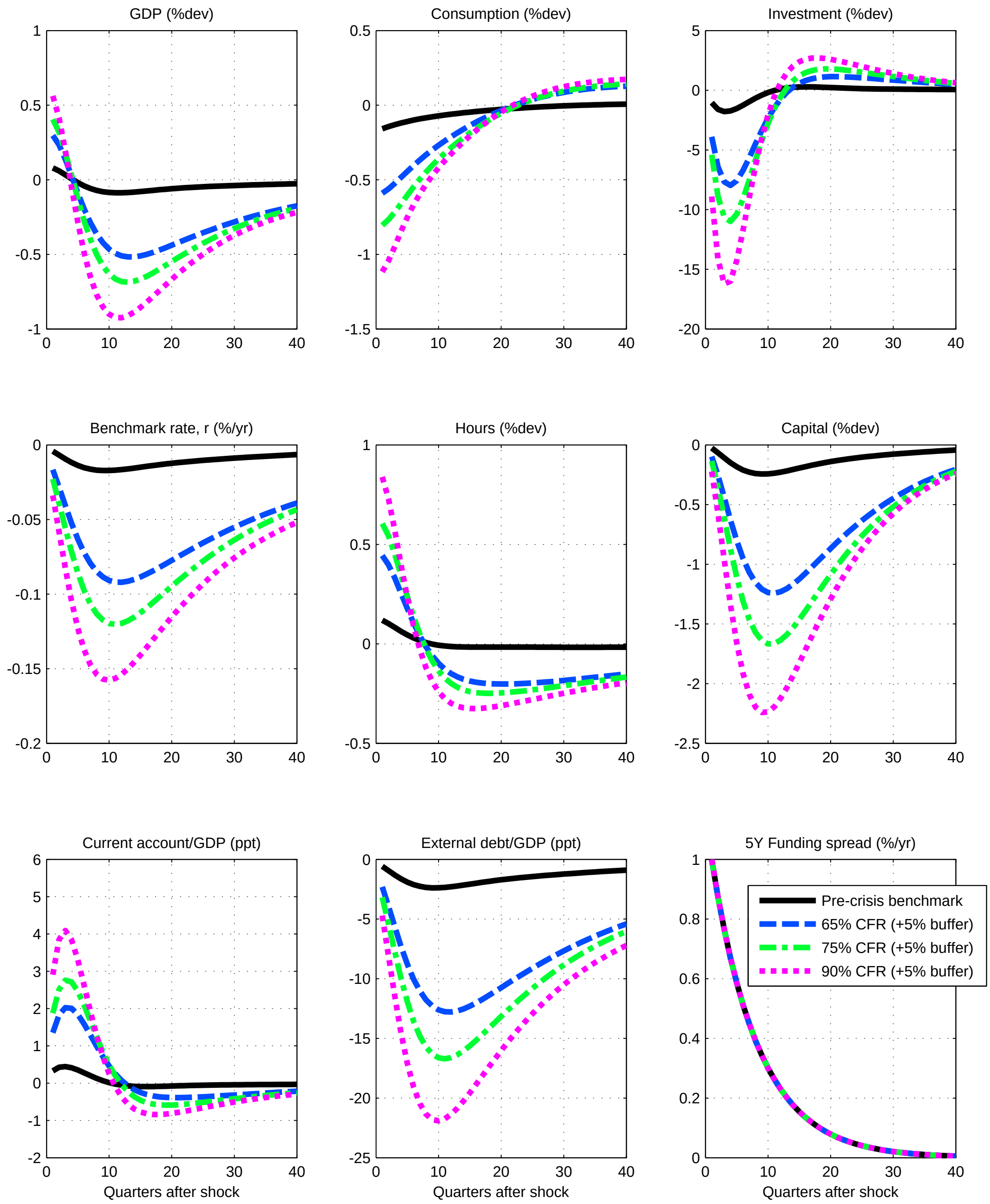
Note: See footnote to Figure 6b

Figure 10
100bp Funding spread shock: effects of steady-state net external debt and the level of the stable funding requirement on the ensuing fall in GDP



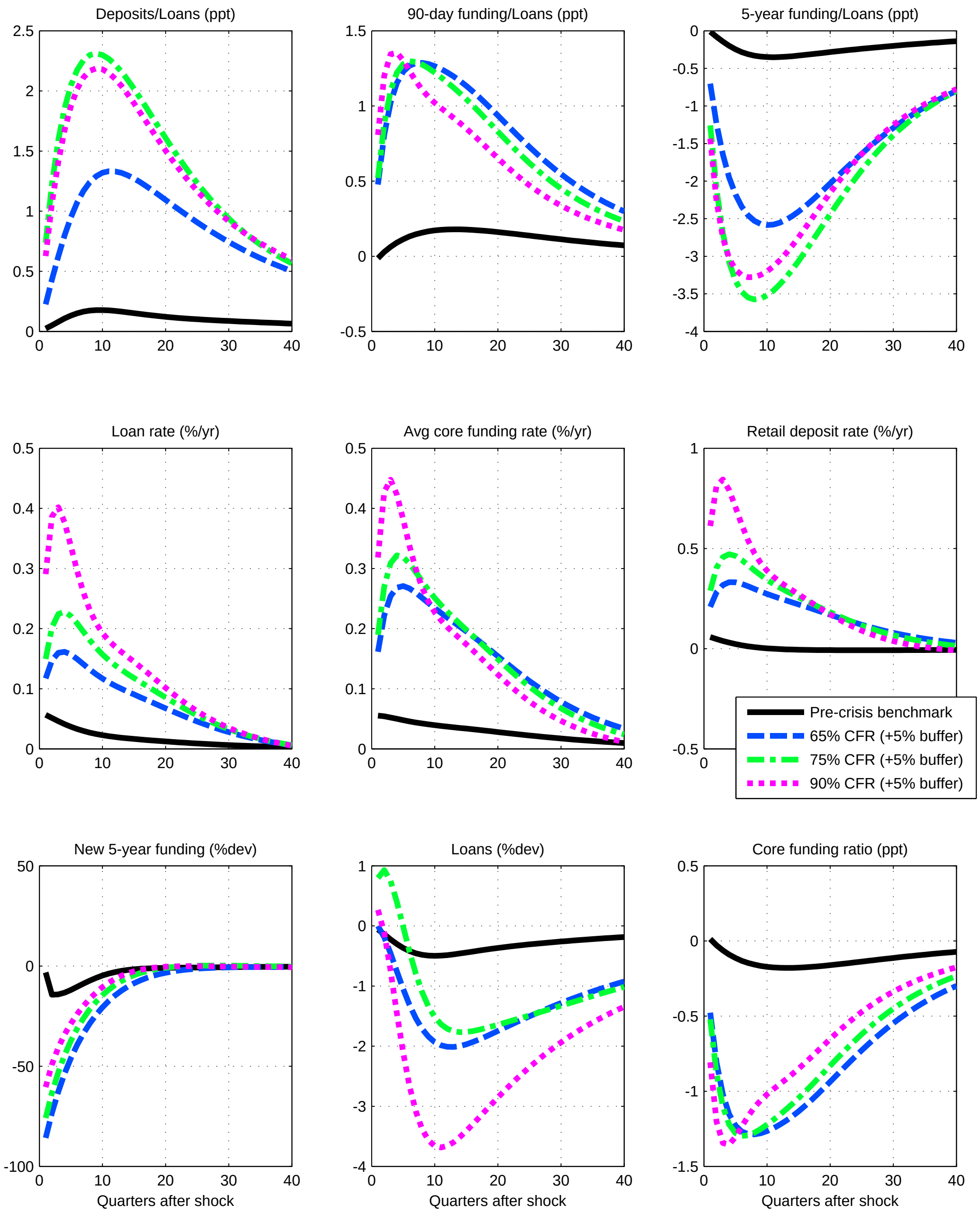
Note: GDP response to a 100bp rise in the 5-year spread.

Figure 11a
IRF: +100bp Funding spread shock, economic variables



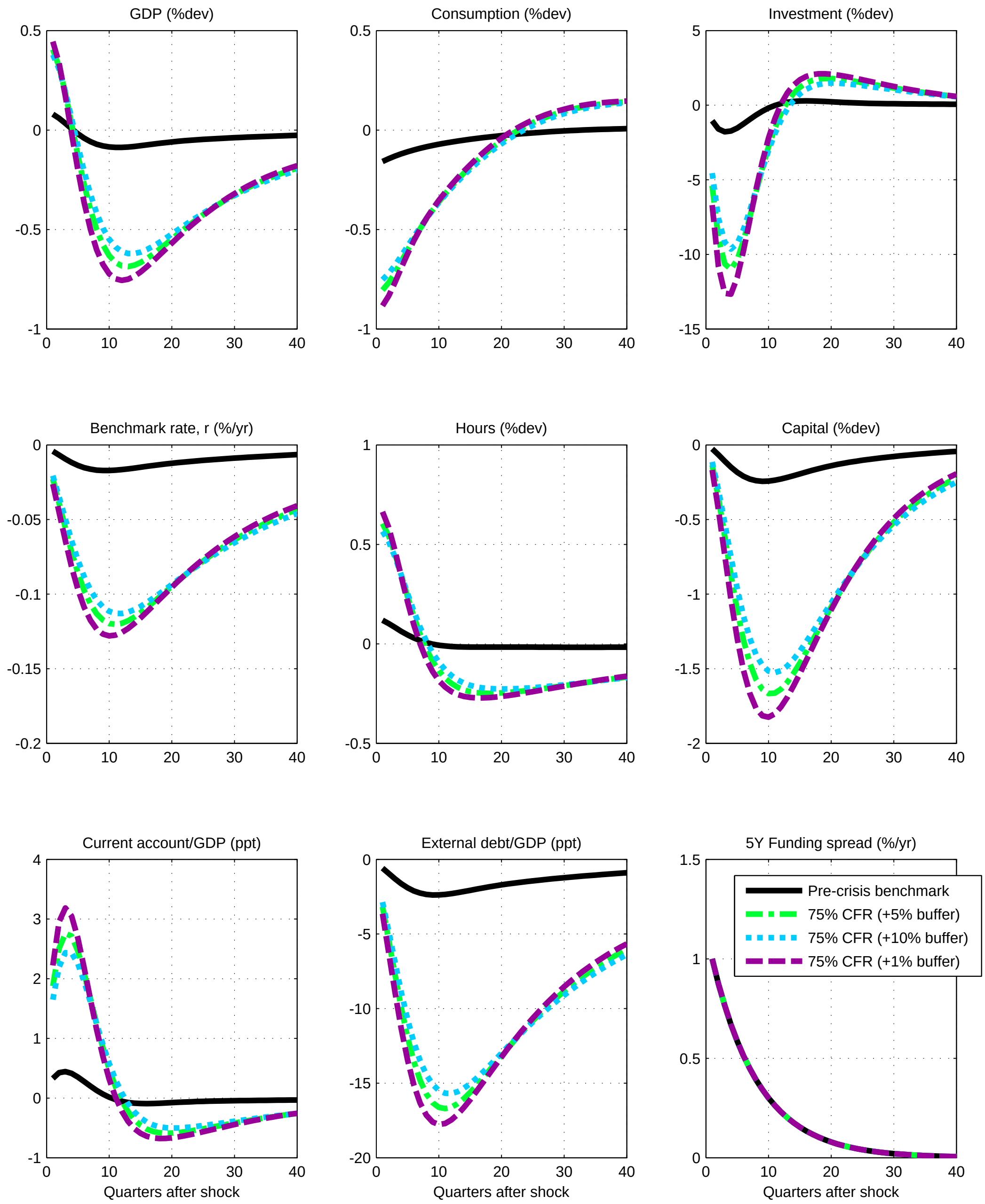
Notes: See footnote to Figure 6a

Figure 11b
IRF: +100bp Funding spread shock, bank variables



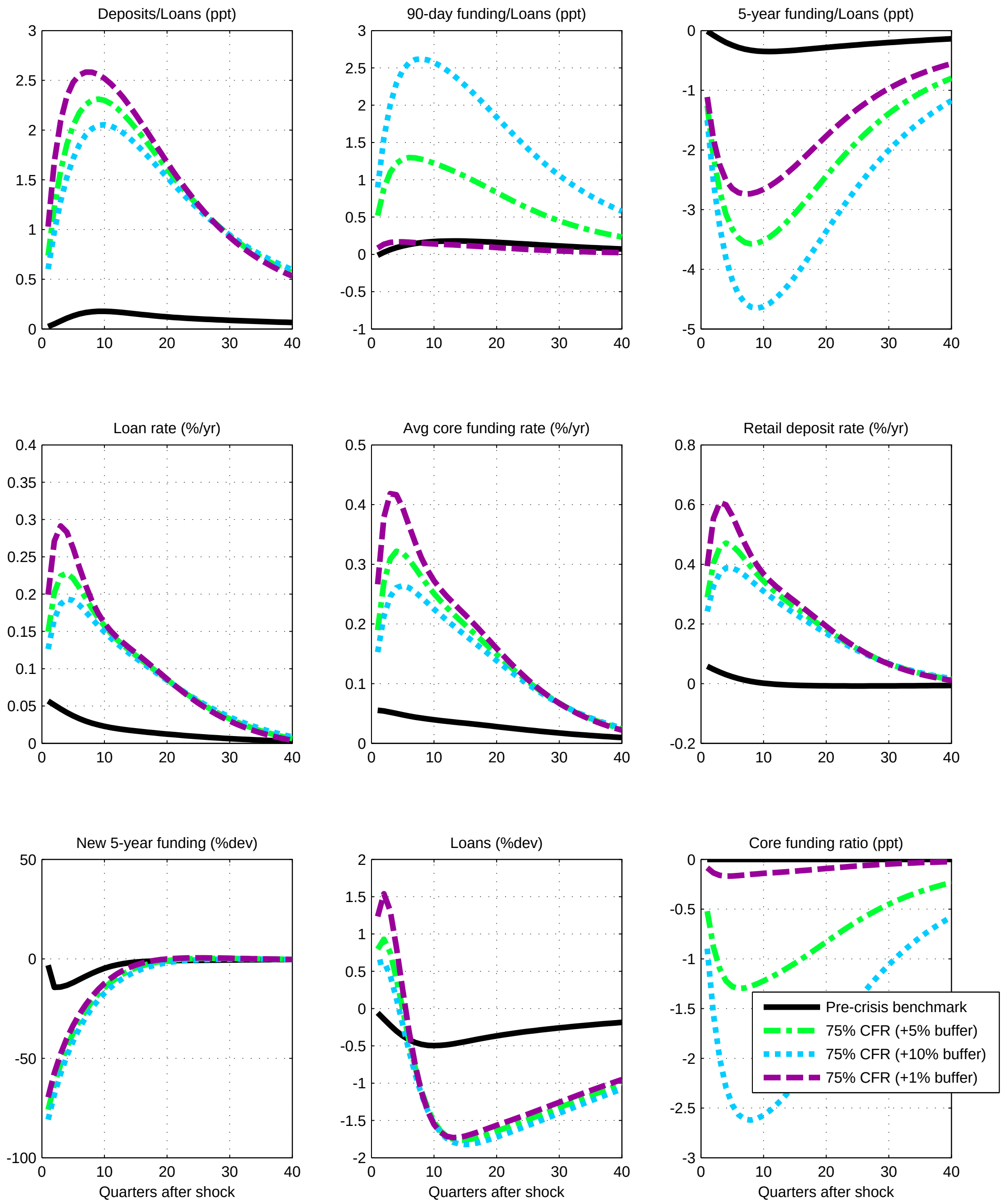
Note: See footnote to Figure 6b

Figure 12a
IRF: Funding spread shock: role of buffers, economic variables



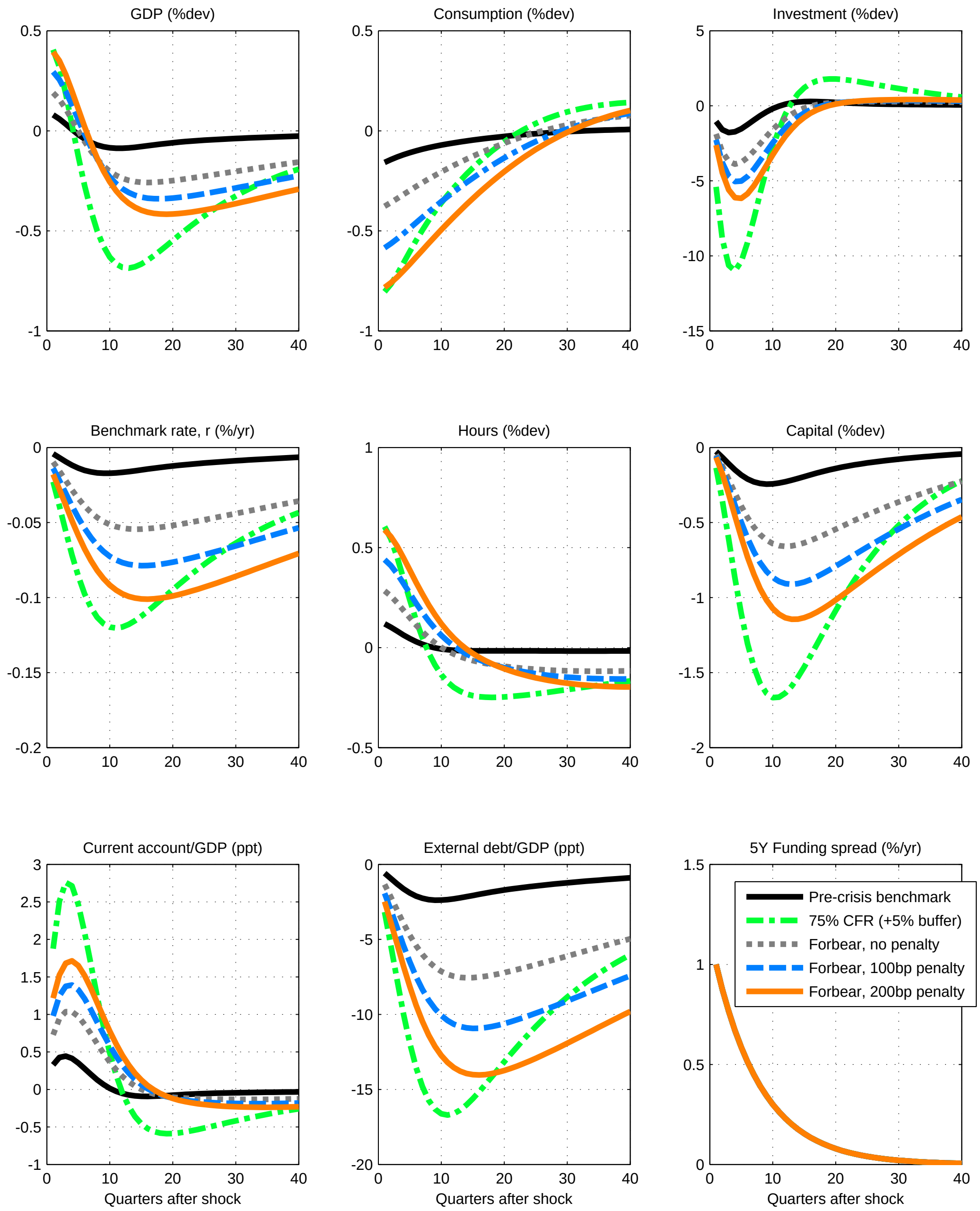
Notes: See footnote to Figure 6a

Figure 12b
IRF: Funding spread shock: role of buffers, bank variables



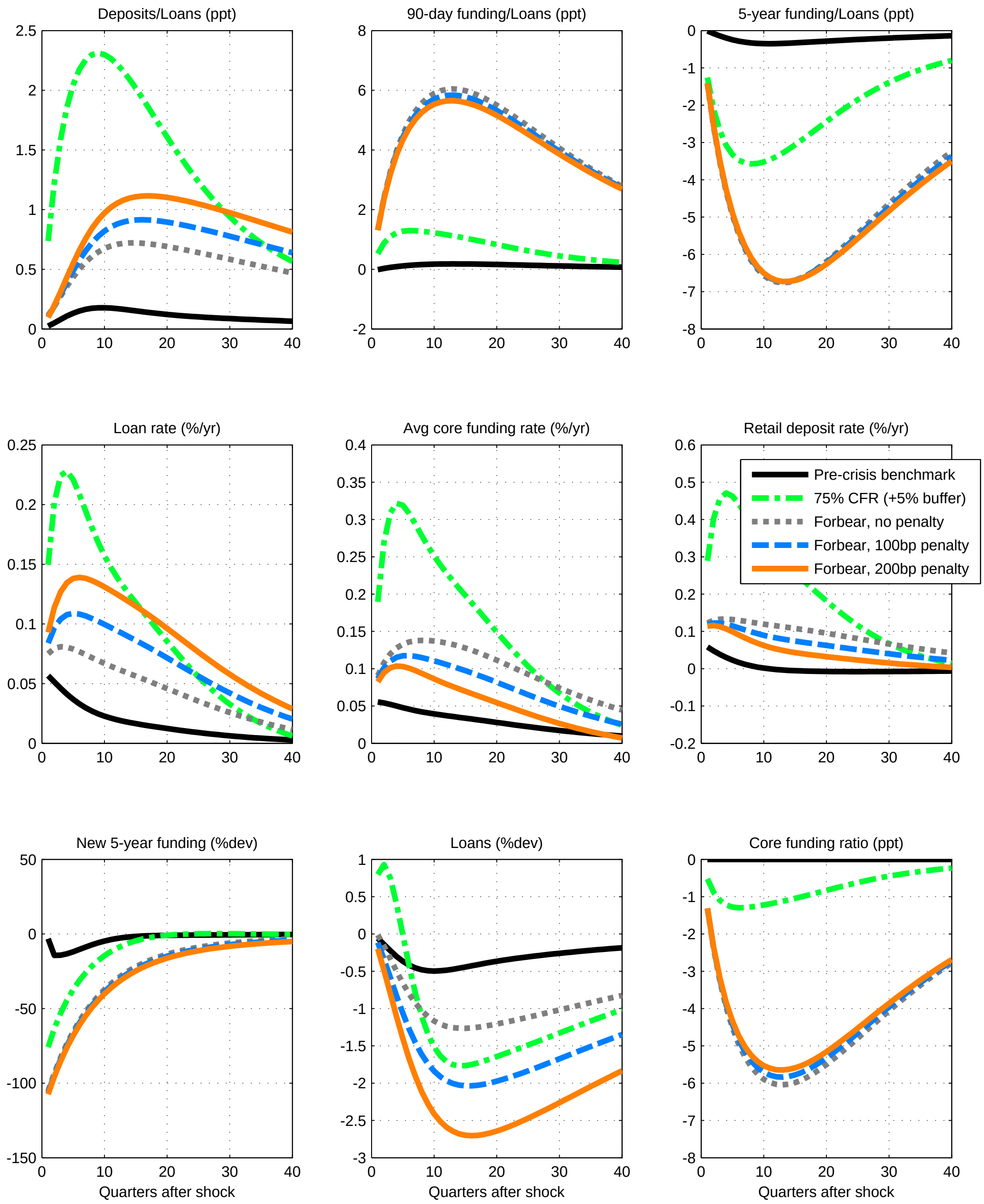
Note: See footnote to Figure 6b

Figure 13a
IRF: Funding spread shock: role of forbearance, economic variables



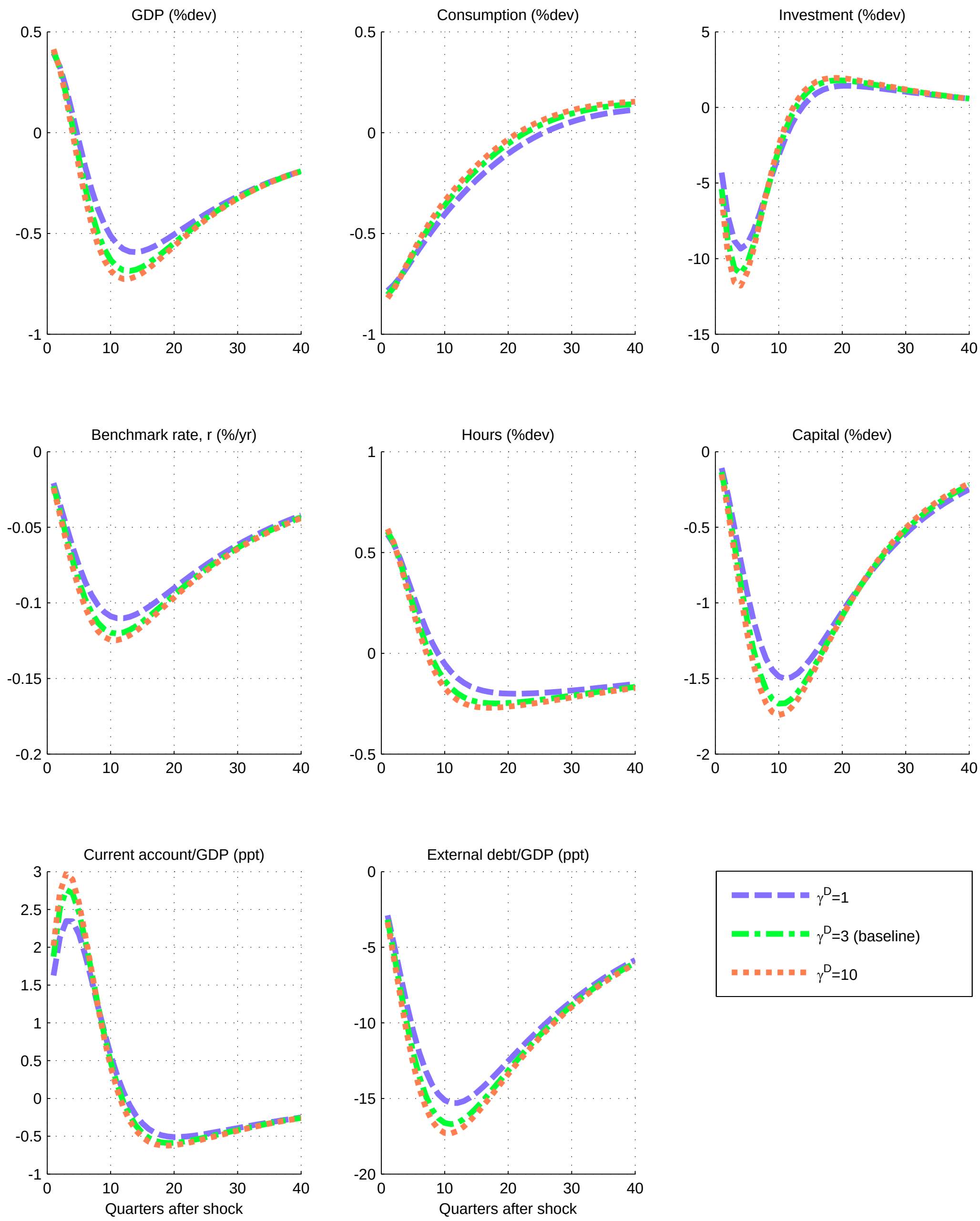
Notes: See footnote to Figure 6a

Figure 13b
IRF: Funding spread shock: role of forbearance, bank variables



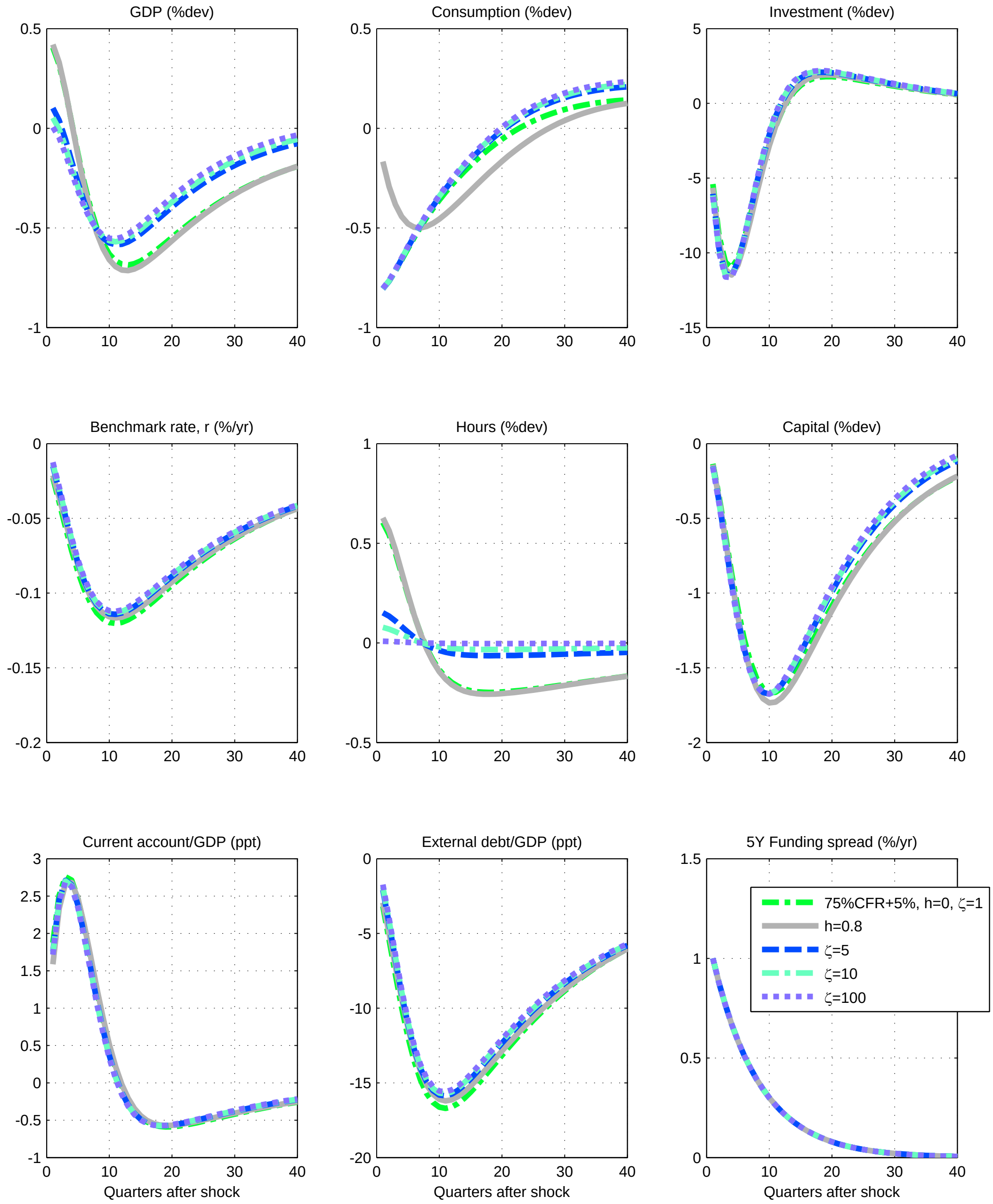
Note: See footnote to Figure 6b

Figure 14
Sensitivity to deposit elasticity (γ^D)



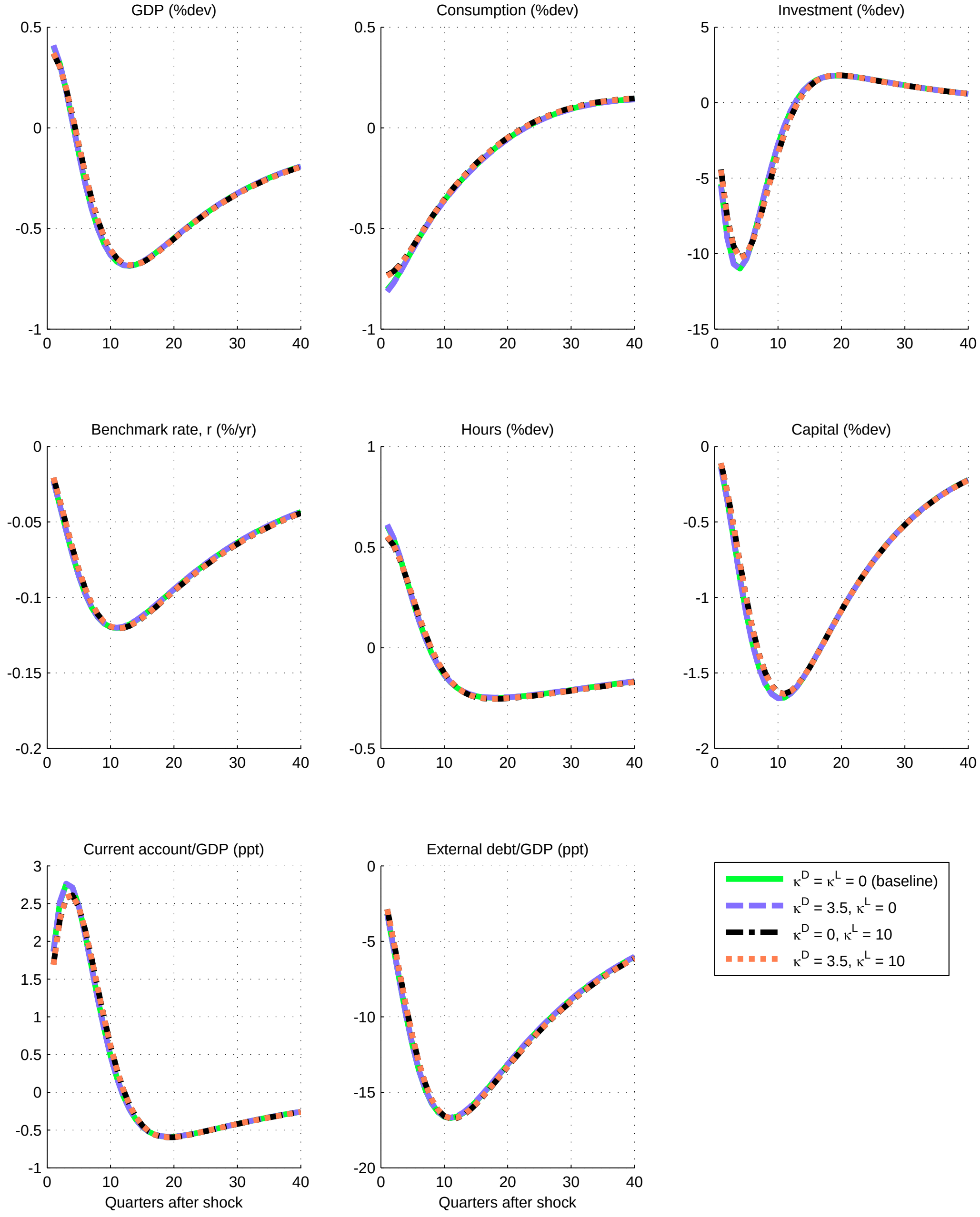
Notes: See footnote to Figure 6a

Figure 15
Sensitivity to consumption habit (h) and labour supply elasticity (ζ)



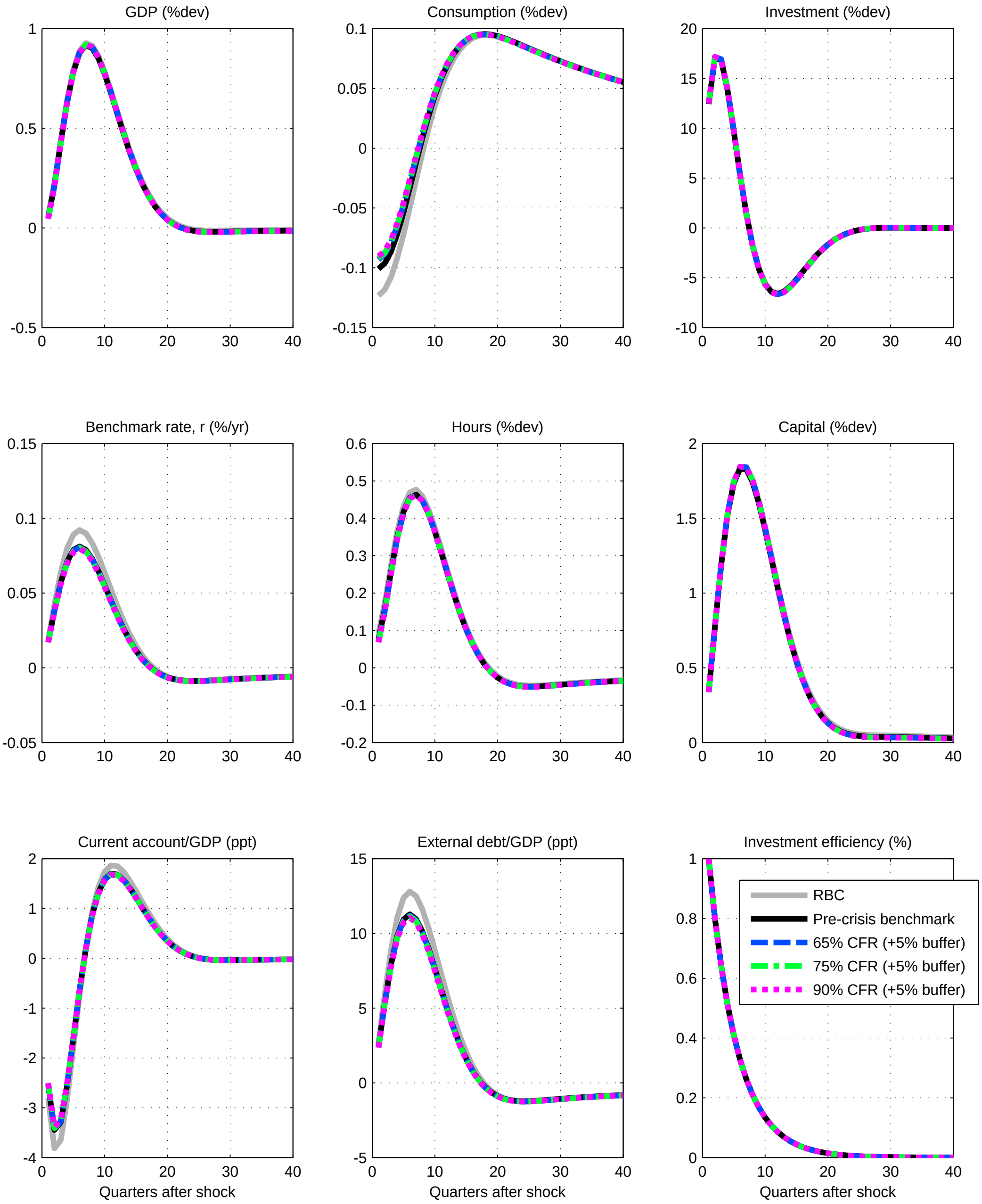
Notes: See footnote to Figure 6a

Figure 16
Stickiness in retail loan and deposit rates



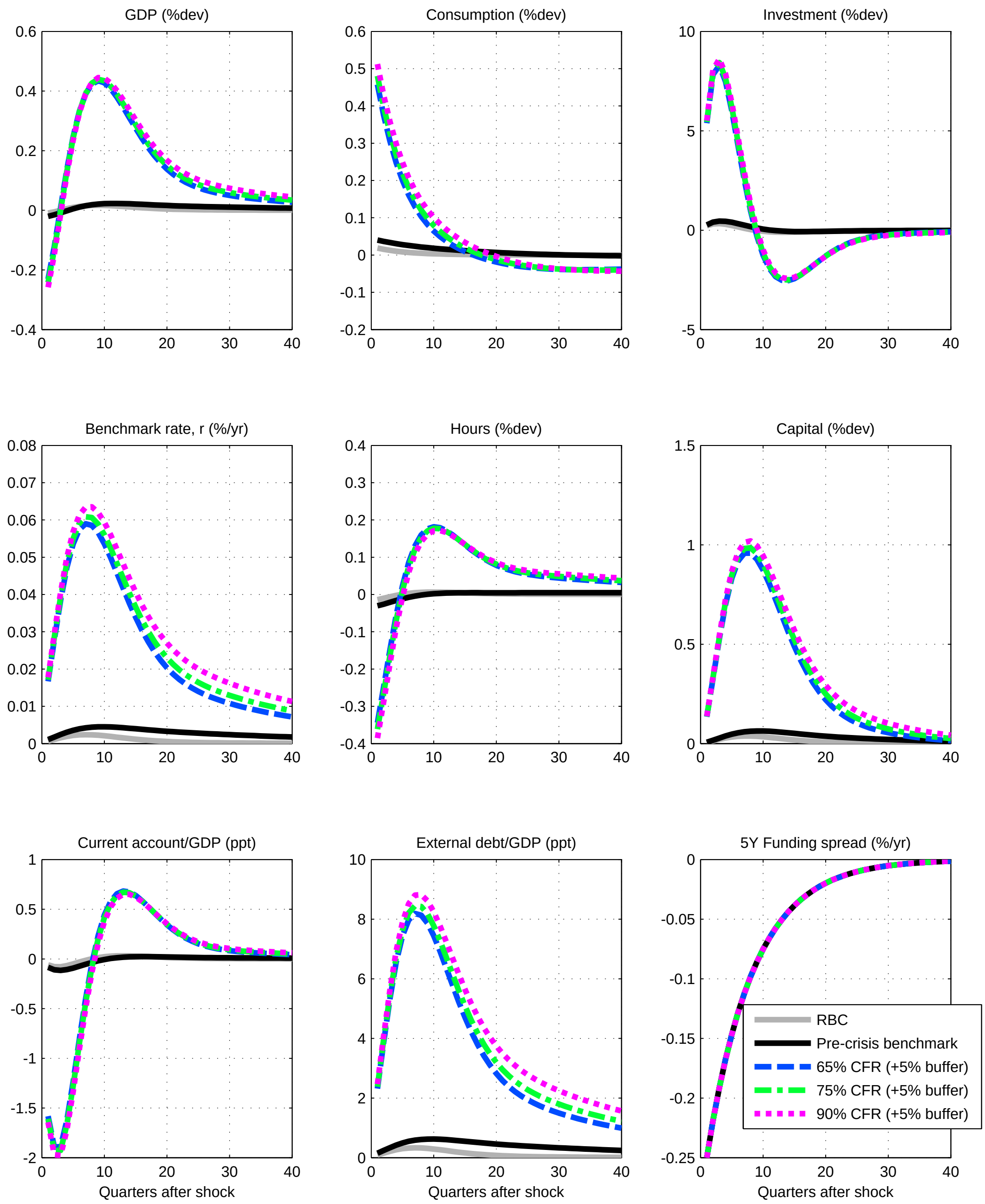
Notes: See footnote to Figure 6a

Figure 17
Investment efficiency shock: No 5-year market adjustment costs ($\kappa^M = 0$)



Notes: See footnote to Figure 6a

Figure 18
Funding spread compression: No 5-year market adjustment costs ($\kappa^M = 0$)



Notes: See footnote to Figure 6a

Appendices

A RBC model with deposits

Household

$$\max_{C_t,N_t,L_t,D_t,I_t,(K_t)} E_t \sum_{t=1}^{\infty} \beta^{t-1} \Big[log(C_t) + \chi \frac{D_t^{1-\gamma}}{1-\gamma} - \nu \frac{N_t^{1+\sigma}}{1+\sigma} \Big] \tag{A.1}$$

$$C_t + D_t + R_{t-1}^L L_{t-1} + I_t + T_t = W_t N_t + L_t + R_{t-1}^D D_{t-1} + \Pi_t^F \tag{A.2}$$

Household first order conditions

$$C_t: \quad \beta \tfrac{U_{t+1}'^C}{U_t'^C} = \Lambda_{t+1} \tag{A.3}$$

$$L_t: \quad 1 = E_t \Big\{ \Lambda_{t+1} \big(1 + r_t^L\big) \Big\} \tag{A.4}$$

$$D_t: \quad 1 - \tfrac{\chi D_t^{-\gamma}}{U_t'^C} = E_t \Big\{ \Lambda_{t+1} \big(1 + r_t^L\big) \Big\} \tag{A.5}$$

$$N_t: \quad W_t = \nu \frac{N_t^\sigma}{U_t'^C} \tag{A.6}$$

Household-owned firm

$$Y_t = \eta_t^A K_t^\alpha N_t^{1-\alpha} \tag{A.7}$$

$$K_{t+1} = (1-\delta) K_t + \eta_t^I S(\frac{I_t}{I_{t-1}}) I_t \tag{A.8}$$

$$\tag{A.9}$$

Firm first order conditions:

$$N_t: \quad W_t = (1-\alpha) \frac{Y_t}{N_t} \tag{A.10}$$

$$\begin{aligned} I_t: \quad 1 &= Q_t^K \Big[S\Big(\tfrac{I_t}{I_{t-1}}\Big) + S'\Big(\tfrac{I_t}{I_{t-1}}\Big) \tfrac{I_t}{I_{t-1}} \eta_t^I \Big] \\ &\quad - E_t \Big\{ \Lambda_{t+1} Q_{t+1}^K S'\Big(\tfrac{I_{t+1}}{I_t}\Big) \frac{I_{t+1}}{I_t} \eta_{t+1}^I \Big\} \end{aligned} \tag{A.11}$$

$$K_t: \quad Q_t^K = E_t \Big\{ \Lambda_{t+1} (\alpha \frac{Y_{t+1}}{K_t} + Q_{t+1}^K (1-\delta)) \Big\} \tag{A.12}$$

Balance of payments. B^e is a liability. The bank is foreign owned.

$$\begin{aligned} B_t^e &= B_t^S + \tilde{B}_t^M \\ &= L_t - D_t \\ B_t^e &= (1 + r_{t-1}^L) L_{t-1} - (1 + r_{t-1}^D) D_{t-1} - NX_t \end{aligned} \tag{A.13}$$

Debt-sensitive one-period benchmark interest rate: $R_t = R_t^* + \varrho \frac{B_t^e}{Y_t}$

B Sticky adjustment of retail rates

In our baseline setup, banks fully pass through the cost of funding to loan rates. This Appendix, describes the introduction of sticky retail loan and deposit rates as in Gerali et al (2010). If the retail units face costs to changing retail rates, then there is gradual pass through of funding costs to retail rates so that banks partially absorb changes to funding costs in their profit margins. Introducing this feature allows us to assess the effect of smoothing the changes in funding costs on our results. Moreover it allows a tractable means of generating slower pass-through to average lending rates that would prevail is retail loans had longer maturities than bank funding.

Lending unit The retail lending unit receives funds from the aggregate funding unit and on-lends the funds to households in a monopolistically competitive environment. Following Gerali et al (2010), the lending unit of bank (j) maximises expected future profits:

$$\max_{r_t^L(j)} E_t \sum_{t=1}^{\infty} \beta^{t-1} \lambda_t^l \left[(r_{t-1}^L(j) - r_{t-1}^l) L_{t-1}(j) - \frac{\kappa^L}{2} \left(\frac{r_t^L(j)}{r_{t-1}^L(j)} - 1 \right)^2 r_t^L L_t(j) \right]$$

subject to loan demand (3).

$L_t(j)$ is the volume of loans made by bank (j), L_t is aggregate loans determined by household loan demand (A.4), $r_t^L(j)$ is the retail lending rate set by bank (j), r_t^l is the average cost of funding,[33] and ϵ^L is the elasticity of loan demand. The term containing κ_L is a quadratic adjustment cost associated with changing the retail lending rate $r_t^L(j)$. This cost leads to stickiness in the retail lending rate.

The first order condition, assuming symmetric equilibrium, is:

$$r_t^L = \frac{\kappa^L r_{t-1}^L + \beta^l \kappa^L E_t[r_{t+1}^L] + (\epsilon^L - 1) r_t^l - \epsilon_t^L}{\epsilon^L - 1 + (1 + \beta^l) \kappa^L} \tag{B.1}$$

where the unit's discount factor is the rate it receives on assets $\lambda^l = 1/(1 + r_t^L)$.

In this set-up, the retail lending rate follows Philips-curve type behaviour, changing only gradually in response to the change in the cost of funds, r_t^l. With fully flexible rates, the retail lending rate is a fixed markup on the cost of funds: $r_t^L = \epsilon^L/(\epsilon^L - 1) r_t^l$. Sticky adjustment to retail lending rates implies sticky adjustment to L_t, beyond the rigidity associated with household loan demand (A.4). In our set-up, we want to know if such stickiness moderates the macroeconomic effects of a stable funding ratio.

Retail deposit unit

Following Gerali et al (2010), the retail deposit unit follows a similar set-up to the retail lending unit. The retail deposit unit maximises expected future profits:

$$\max_{r_t^D(j)} E_t \sum_{t=1}^{\infty} \beta^{t-1} \lambda_t^d \left[(r_{t-1}^d - r_{t-1}^D(j)) D_{t-1}(j) - \frac{\kappa^D}{2} \left(\frac{r_t^D(j)}{r_{t-1}^D(j)} - 1 \right)^2 r_t^D D_t(j) \right]$$

[33] Uppercase superscripts denote rates between the bank and other agents, and lowercase superscripts denote unobserved rates internal to the bank.

subject to demand for the unit's differentiated deposit contract (3), where aggregate deposit demand D_t is given by equation (A.5). The first order condition, assuming symmetric equilibrium, is:

$$r_t^D = \frac{\kappa^D r_{t-1}^D + \beta^d \kappa^D E_t[r_{t+1}^D] + (\epsilon^D - 1) r_t^d + \epsilon_t^D}{\epsilon^D - 1 + (1 + \beta^d)\kappa^D} \tag{B.2}$$

where the unit's discount factor is the marginal return on assets $r^d = r^c$. Adjustment costs (term in κ^D) associated with changing the deposit rate lead to stickiness in adjustment of the retail deposit rate. Sticky adjustment in the retail deposit rate, implies sticky adjustment to the quantity of deposits (A.5). With fully flexible rates, $\kappa^D = 0$, the retail deposit rate is a fixed markdown on the rate paid by the core funding unit, $r_t^D = \epsilon^D/(\epsilon^D - 1) r_t^d$. In a perfectly competitive market, (large ϵ^D), the markdown becomes very small.

In the benchmark model, κ^D and κ^L are zero so that funding costs are fully passed through each period. For partial adjustment of retail rates, the values estimated by Gerali et al (2010) for the Euro area ($\kappa^D = 3.5$ and $\kappa^L = 10$) are used.