The macroeconomic effects of a stable funding requirement

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Abstract

This paper examines the macroeconomic effects of a bank stable funding requirement of the type proposed under Basel III and introduced in New Zealand in 2010. The paper sets out a small open economy model incorporating a banking sector funded by retail deposits and short- and long-term wholesale borrowing, with a tractable setup for multi-period debt that allows hedging of benchmark interest rate risk. A stable funding requirement increases rollover in long-term funding markets, despite lower aggregate rollover. Greater exposure to long-term funding markets attenuates credit expansion if funding costs rise more steeply with volumes in less-liquid long-term markets. However, it amplifies the pro-cyclical effects of fluctuations in funding spreads because variations in long-term spreads are larger and are carried for the duration of the funding (cannot be hedged). Such amplification increases in the level of the requirement and the level of net debt. We explore approaches to moderating adverse macroeconomic outcomes.

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1 Introduction

Central banks act as lenders of last resort to prevent liquidity pressures from becoming solvency problems.\(^1\) The availability of liquidity “insurance”, however, can reduce the incentive for banks to raise relatively expensive stable funding and lead banks to underinsure against refinancing risk (moral hazard). In periods when credit has grown rapidly, retail deposits have tended to grow more slowly and banks have shifted toward less stable short-term wholesale funding. 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 by increasing rollover requirements and by lengthening intermediation chains via funding from other financial institutions.

In response to the systemic liquidity stress experienced during the 2008 global financial crisis (GFC), extensive liquidity support was provided to banks (reinforcing moral hazard), and stronger liquidity regulation has been proposed\(^2\) to increase banks’ self insurance against liquidity crises.\(^3\) These liquidity regulations include minimum stable funding ratios\(^4\) – the net stable funding ratio (NSFR) under Basel III and New Zealand’s core funding ratio (CFR)\(^5\) – that require banks to raise a larger share of stable funding in the form of retail deposits and/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

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\(^1\) The lender of last resort literature goes back to Thornton (1802) and Bagehot (1873). Much of the recent literature builds on Diamond and Dybvig (1983). See Freixas et al (2000) for a review.

\(^2\) Basel III liquidity requirements are scheduled to come into force in 2018 (see http://www.bis.org/bcbs/basel3.htm). The Reserve Bank of New Zealand liquidity policy was introduced in April 2010 (see http://www.rbnz.govt.nz/finstab/banking/). These policies include liquid asset ratios and maturity mismatch ratios as well as stable funding requirements.

\(^3\) Other approaches to liquidity regulation include a liquidity overlay on capital regulation (see Brunnermeier et al (2009)), and price-based approaches (eg. Pigouvian taxes). Bagehot (1873) argued that central bank liquidity provision should be provided at a penalty rate to reduce the moral hazard problem. 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.

\(^4\) Here 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.

\(^5\) The NSFR and CFR differ in their details, but are similar in overall effect.
setup for multi-period funding that allows the bank to shed benchmark interest rate risk;\(^6\) and (iii) using this framework, the paper examines the macroeconomic effects of a stable funding requirement.

The introduction of a stable funding requirement increases funding costs because (i) long-term wholesale funding is more expensive than short-term wholesale 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 in steady state.

A stable funding requirement can moderate credit growth. If funding costs rise with volumes more steeply in less-liquid long-term funding markets than in short-term funding markets, then a stable funding requirement increases the cost of expanding credit. This effect is reinforced when deposits are an explicit substitute for long-term funding because rising long-term funding costs are passed through to retail funding costs.

A stable funding requirement, however, amplifies the pro-cyclical effects of variations in wholesale funding spreads (spreads between wholesale funding costs and the interest rate swap of the same maturity). Wholesale funding spreads tend to be compressed during credit booms and to expand during systemic funding market stress (see Figure 1). A stable funding requirement increases the required rollover in long-term markets (despite the lower rate of rollover overall, see Figure 2), increasing banks' exposure to these markets. Long-term funding spreads matter a lot 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 (unlike the benchmark, they cannot be hedged). This amplification is increasing in the level of the stable funding requirement and the small open economy's 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. a macro-prudential overlay) for the same reasons that motivate a counter-cyclical capital overlay: to avoid high costs of meeting the requirement in a crisis and to facilitate use of buffers that have been built up in good times.

\(^6\) Financial institutions routinely use the interest rate swap market to shed benchmark interest rate risk (to match the fixed/floating interest rate structure of their assets and liabilities). See Craigie (2012) for an empirical study of interest rate risk for Australian and New Zealand banks.
The rest of the paper is set out as follows: Section 2 provides a brief review of the related 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 bond spreads, and section 6 considers the roles of ex-ante buffers, ex-post forbearance and counter-cyclical application of the requirement in mitigating that amplification. Section 7 examines sensitivity of the results to key parameters and section 8 concludes.

2 Related literature


Second, this paper contributes to the overlapping literature that assesses the

\(^7\) 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 include Brunnermeier and Sannikov (2009), He and Krishnamurthy (2010) and Bianchi and Mendoza (2010) which feature occasionally binding constraints and episodes of financial instability.
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. In contrast, a growing general equilibrium model-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. While the linear models 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. Papers 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 Vlcek (2011) which examines a liquid asset ratio. In contrast, this paper examines a stable funding requirement on the liability-side. 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 and the finance literature. Benes and Lees (2010) use a similar structure 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 can imply a large degree of interest rate risk (and associated valuation effects). Modern banks use interest rate swaps to hedge benchmark 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 a standard
open economy RBC model. The open economy RBC model (Appendix A) is
based on a representative household that is a net debtor, and is closed with
a debt-sensitive risk premium. Setting the policy in a simple, flexible price
model allows us to focus on the dynamics of the funding cost wedge and on
the general effects of that wedge on the economy in the absence of offsetting
monetary policy. The absence of monetary policy allows us to elaborate the
full effects of the stable funding ratio in isolation. The important interaction
with monetary policy is left for further work.

The model bank intermediates between households and external wholesale
funding markets. The bank raises three types of funding: one-period retail
deposits, one-period wholesale funding, and multi-period bonds from external
wholesale markets; and provides floating rate loans to households (at cost).
Wholesale funding is subject to a funding spread (to swap\textsuperscript{12}) that is increasing
in the duration of the funding and subject to liquidity effects that are more
severe in less-liquid long-term markets. Banks hedge benchmark interest rate
risk through the interest rate swap market.

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

\textsuperscript{12} The swap rate is the fixed interest rate that equates, ex-ante, the present value of fixed
payments to the present value of floating-rate payments on a standard instrument such
as 3-month Libor, or in New Zealand, a 3-month bank bill. The value of the fixed-rate
payment stream is subject to valuation effects as short-term rates deviate over the
contract period.
achieve that.\textsuperscript{13} The representative household maximises expected utility:

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

subject to the budget constraint:

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

The household uses inflows from wage income $W_t N_t$, new loans $L_t$, last period’s deposits plus interest $R_{t-1}^D D_{t-1}$, and firm profits $\Pi_t^F$ to finance consumption $C_t$, investment $I_t$, new deposits $D_t$, repayment of principal and interest $R_{t-1}^L L_{t-1}$ and lump sum taxes. This setup yields the usual first order conditions (Appendix A) plus the following demand for deposits:

$$
\chi \frac{1}{D_t} = \left( 1 - \frac{E_t(\Lambda_{t+1} R_t^D)}{E_t(\Lambda_{t+1} R_t^L)} \right) U_t^{c,t}
$$

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 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 loan unit lends available funds to households;
- an aggregate funding unit combines core- and non-core funding;

\textsuperscript{13} Although somewhat ad hoc, 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. See Sidrauski (1967) for the seminal paper and the cash-in-advance money models of Lucas and Stokey (1987) and Cooley and Hansen (1989). In a DSGE model with a bank, De Walque et al (2010) include deposits in the utility function in a different functional form. Deposits could, instead, 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). In practice, borrowers tend to hold deposits and are sometimes required to do so. 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.
• a core funding unit combines retail deposits and long-term wholesale funding;
• and a retail deposit unit raises retail deposits.

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

<table>
<thead>
<tr>
<th>Assets</th>
<th>Liabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail loans (90-day)</td>
<td>90-day wholesale funding (non-core)</td>
</tr>
<tr>
<td></td>
<td>5-year wholesale funding (core)</td>
</tr>
<tr>
<td></td>
<td>90-day retail deposits (core)</td>
</tr>
</tbody>
</table>

**Aggregate funding unit**

The aggregate funding unit combines core (stable) funding, $B^c_t$, with non-core (short-term wholesale) funding, $B^S_t$, into a floating-rate loan $L_t$ which is provided to households. Although setup here as a one-period loan, the duration of the loan is implicitly the average duration of the bank’s funding.\(^{14}\) The aggregate funding unit chooses the quantities of core and non-core funding that maximise expected profits:

\[
\max_{B^c_t, B^S_t} E_t \sum_{t=1}^{\infty} \beta^{t-1} \lambda_t^r \left[ B^c_t + B^S_t + (1 + \lambda_{t-1}^l) L_{t-1} - L_t - (1 + \lambda_{t-1}^a) B^c_{t-1} - (1 + \lambda_{t-1}^S) B^S_{t-1} - \frac{\kappa^{cfr}}{2} \left( \frac{B^c_t}{L_t} - \nu^{cfr} \right)^2 B^c_t \right]
\]

subject to the balance sheet constraint $L_t = B^c_t + B^S_t$ and the regulatory requirement embodied in $\nu^{cfr}$, where $\lambda_{t}^a$ is the average cost of core funding paid to the core funding unit, $\lambda_{t}^S$ is the rate paid on one-period wholesale funding, and the term containing $\kappa^{cfr}$ is a quadratic adjustment cost associated with deviating from the desired core funding ratio, $\nu^{cfr}$. $\nu^{cfr}$ can be thought of as

\(^{14}\) The bank offers the loan at cost. The average rate on many overlapping mortgages priced at the marginal cost is the same as the rate on a mortgage priced at the bank’s average cost of funds. In practice, and particularly in the absence of guarantees for long-term fixed-rate contracts (eg. via Fannie and Freddie in the US), loans are typically repriced several times within the mortgage maturity. In addition, if the bank smooths its lending rates, changes in the bank’s marginal costs are only gradually passed through to lending rates. If loan rates, and so households decisions, were instead based on the marginal cost of bank funding, there could be considerably larger short-term effects of funding spreads on those households repricing their loans.

\(^{15}\) Here the bank has no maturity mismatch. Maturity mismatch could be introduced by setting up a separate (fixed- or floating-rate) multi-period structure on the lending side. Alternatively, sticky adjustment of loan rates as in (Gerali et al 2010) would have a similar effect, leading that bank to smooth changes in funding costs, and loan volumes.
the bank’s desired core funding ratio determined by internal risk management, by pressure from markets or by explicit regulation. In the absence of the quadratic cost term, the bank would seek to fund only from short-term markets.

The first order conditions define the spreads between the loan rate (the average cost of funding) $r^l_t$, and the cost of core and non-core funding.

$$r^l_t - r^S_t = -\kappa c^f r \left( \frac{B^c_t}{L_t} - \nu c^f r \right) \left( \frac{B^c_t}{L_t} \right)^2$$ (4)

$$r^a_t - r^S_t = -\kappa c^f r \left( \frac{B^c_t}{L_t} - \nu c^f r \right) \frac{B^c_t}{L_t}$$ (5)

Combining (4) and (5), the interest rate on aggregate funding can be expressed as a weighted average of the short-term wholesale rate, $r^S_t$, and the rate paid for core funding, $r^a_t$:

$$r^l_t = (1 - \frac{B^c_t}{L_t}) r^S_t + \frac{B^c_t}{L_t} r^a_t$$ (6)

**Core funding unit**

The core funding unit produces core funding, $B^c_t$, by combining one-period retail deposits, $D_t$, and its stock of unmatured multi-period bonds, $\tilde{B}^M_t$, available at time $t$, and on-lends the funds to the aggregate funding unit at the average cost of core funding, $r^a_t$. The balance sheet constraint is:

$$D_t + \tilde{B}^M_t = B^c_t$$ (7)

Systemic funding market stress is treated as exogenous in our open-economy setup. New bonds, $B^M_t$, of fixed duration, $m$, are issued in external capital markets at time, $t$, at the floating benchmark rate plus a funding spread (to swap) that is fixed at the time of issuance and cannot be hedged. The funding spread $m \tau_t$ is increasing in the duration of the funding, consistent with observed spreads (Figure 1), and varies over time. $\tau_t$ is assumed to evolve according to an AR1 process $\tau_t = \tau_{t-1} + \tau(1-\rho^\tau) e^{\tau_t}, \ e^{\tau_t} \sim N(0, \sigma^\tau)$.

The cost of one-period external wholesale funding ($m = 1$) is the benchmark rate plus a small external funding spread: $r^S_t = r_t + \tau_t$.

---

16 The bonds are assumed to be issued in domestic currency (or in foreign currency and swapped into local currency) and purchased by non-residents.

17 Fixed-coupon payments/receipts are assumed to be swapped to floating-coupon payments/receipts at the one-period benchmark rate plus a fixed spread.

18 In practice, $\tau_t$ is a skewed shock process.
For tractability, it is useful to divide the bond repayments in two parts: (i) fixed principal repayments plus the fixed spread, and (ii) floating rate coupon payments. Repayment of principal and the fixed spread on funding $B_t^M$ raised at time $t$, is paid at a decaying rate. This perpetuity structure is based on the setup introduced in macro-models by Woodford (2001) and elaborated in Benes and Lees (2010) to include a floating coupon component. Total payments on debt raised at time $t$ are as follows:

\[ t + 1 : \quad (Q_t + r_t)B_t^M \]
\[ t + 2 : \quad \delta^M (Q_t + r_{t+1})B_t^M \]
\[ t + 3 : \quad (\delta^M)^2(Q_t + r_{t+2})B_t^M \]
\[ \vdots \quad \vdots \]

where $Q_t$ is the fixed payment related to principal and the fixed spread on long-term debt raised at time $t$. $Q_t B_t^M$ covers the principal repayment $(1 - \delta^M)B_t^M$ and the fixed spread $m\tau_t B_t^M$, so that

\[ Q_t = (1 - \delta^M + m\tau_t) \quad (8) \]

The sum of repayments of the principal plus the fixed spread on all past wholesale funding due at time $t$ (excluding floating interest payments) is

\[ J_{t-1} = \sum_{k=1}^{\infty} (\delta^M)^{k-1} Q_{t-k} B_{t-k}^M \quad (9) \]

which can be written in recursive form:

\[ J_t = \delta^M J_{t-1} + Q_t B_t^M \quad (10) \]

The book value of the principal declines at a rate $\delta^M$, so that the law of motion of the stock of unmatured bonds $\tilde{B}_t^M$ is:

\[ \tilde{B}_t^M = \delta^M \tilde{B}_{t-1}^M + B_t^M \quad (11) \]

The duration of the funding is the present value of repayments discounted at the rate of return on assets $PV_{t+k} = (\delta^M)^{k-1}(Q_t + r_{t+k})\left[\frac{1}{R_{t+k-1}}\right]$, weighted by time to maturity:

\[ m = E_t \sum_{k=1}^{\infty} k PV_{t+k} / E_t \sum_{k=1}^{\infty} PV_{t+k} \]

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:

\[ r_t^a B_t^c = r_t^d D_t + [J_t - (1 - \delta^M) \tilde{B}_t^M] + r_t \tilde{B}_t^M \]  

(12)

where the final term captures the floating rate benchmark payments.

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

At time \( t \), the core funding unit receives funds lent to the aggregate funding unit at \( t - 1 \) plus interest (at a rate \( r_{t-1}^r \)), issues new bonds \( B_t^M \) and raises deposits \( D_t \). It repays the deposit unit with interest, repays maturing principal and interest on outstanding bonds issued before time \( t \), \( (J_{t-1} + r_{t-1} B_{t-1}^M) \), and is subject to adjustment costs if it expands funding from less-liquid long-term markets. The core funding unit chooses deposits and new bonds to maximise the expected stream of future profits:

\[
\max_{B_t^c, D_t, B_t^M, J_t, \tilde{B}_t^M} E_t \sum_{t=1}^{\infty} \beta^{t-1} \lambda_t^c \left[ B_t^M + D_t + (1 + r_{t-1}^c) B_{t-1}^c - B_t^c - J_{t-1} - r_{t-1} \tilde{B}_{t-1}^M - (1 + r_{t-1}^d) D_{t-1} - \frac{\kappa^M}{2} \left( \frac{\tilde{B}_t^M}{B_{t-1}^M} - 1 \right)^2 B_t^M \right]
\]  

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.

The term containing \( \kappa^M \) is a quadratic adjustment cost associated with changing the stock of bonds raised. We think of this as a relative liquidity effect: prices respond to volumes by more in less-liquid long-term markets than in short-term 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.\(^\text{19}\) \(^\text{20}\) These adjustment costs imply that the supply of long-term funding is steep in the short run and flat

\(^{19}\) Such a cost could also represent higher marketing/roadshow costs or commitment issues related to debt repayment. See Arellano and Ramararayanan (2008) for a model where investors prefer short-term funding for control reasons (as borrowers cannot commit to not increasing debt during the term of the debt), but provide a small amount of long-term funding to reduce borrowers’ liquidity risk.

\(^{20}\) For New Zealand banks, such costs relate not only to net issuance in foreign debt markets, but also to markets for hedging foreign currency exposure.
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 $\lambda_{t+k}^c$, the law of motion for $J_{t+k}$ a Lagrange multiplier $\lambda_{t+k}^c \Psi_{t+k}$, and the law of motion for $\tilde{B}_{t+k}$ a multiplier $\lambda_{t+k}^c \Phi_{t+k}$, the first order conditions are:

\begin{align*}
B_t^c & : \quad 1 = \beta E_t \left\{ \frac{\lambda_{t+1}^c}{\lambda_t^c} (1 + r_t^c) \right\} \quad (14) \\
D_t & : \quad r_t^c = r_t^d \quad (15) \\
B_t^M & : \quad 1 = \Psi_t Q_t + \Phi_t \quad (16) \\
J_t & : \quad \Psi_t = \beta E_t \left\{ \frac{\lambda_{t+1}^c}{\lambda_t^c} (1 + \delta^M \Psi_{t+1}) \right\} \quad (17)
\end{align*}

\begin{equation}
\tilde{B}_t^M : \quad \Phi_t = \beta E_t \left\{ \frac{\lambda_{t+1}^c}{\lambda_t^c} (r_t + \delta^M \Phi_{t+1}) \right\} + \kappa^M \left( \frac{\tilde{B}_{t+1}^M}{B_{t+1}^M} - 1 \right) \frac{B_t^M}{B_{t-1}^M} - \frac{\kappa^M}{R^c} \left( \frac{\tilde{B}_{t+1}^M}{B_{t+1}^M} - 1 \right) \frac{B_{t+1}^M}{B_t^M} \quad (18)
\end{equation}

According to (14) the unit discounts at the marginal return on assets. According to (15), the marginal cost of a unit of core funding is equal to the cost of a one-period retail deposit.

According to (16), the value of a bond is equal to the expected sum of repayments of principal and fixed spread payments, $Q_t \Psi_t$, plus the expected value of future floating rate interest payments, $\Phi_t$, net of long-term market adjustment costs. 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 (16) can be understood by writing the total stream of payments on a bond $B_t^M$ issued at time $t$ as:

\begin{equation}
B_t^M = Q_t B_t^M E_t \sum_{k=1}^{\infty} \frac{(\delta^M)^{k-1}}{R_t^c \ldots R_{t+k-1}^c} + B_t^M E_t \sum_{k=1}^{\infty} \frac{(\delta^M)^{k-1} \Gamma_{t+k-1}}{R_t^c \ldots R_{t+k-1}^c} \quad \Psi_t \quad \Phi_t
\end{equation}

According to (17) and (18) $\Psi_t$ and $\Phi_t$ can be expressed recursively. $\Psi$ follows directly from Benes and Lees (2010), while $\Phi$ allows the bank to shed benchmark interest rate risk.
For one-period funding \((m = 1, \delta^M = 0)\) this reverts to the standard one-period setup.

Combining (15) to (18), and abstracting from adjustment costs (terms in \(\kappa^M\)), the marginal value of one-period retail deposit can be written as a function of the long-term wholesale spread:

\[
\begin{align*}
    r_d^t &= r_t + m \left[ \bar{\tau} + \tau_t \left( 1 + \delta^M (1 - \rho^\tau) \Psi_{t+1} \right) \right]
\end{align*}
\]  

(19)

The marginal value of a retail deposit, \(r_d^t\), is the benchmark rate plus a multiple of the observed wholesale spread. The multiple is increasing in the duration of the wholesale funding (via \(m\) and \(\delta^M\)) and falling in the persistence of the spread \(\rho^\tau\). Intuitively, the expected cost of raising core funding through issuing an \(m\)-period bond today equals the expected cost of raising a one-period retail deposit this period and issuing a slightly smaller \((m - 1)\) period bond \(\delta^M B^M_t\) next period, taking into account the smaller spread on the smaller and shorter bond, and the expected decay of the AR1 funding spread. If the term spread is high (eg. in the event of systemic stress), then the bank will be willing to pay considerably more for a retail deposit to put off raising a bond for another period if the final term in (19) is large.

The pass-through from higher funding costs to higher lending rates depends on the share of core funding, and on the persistence of the spread. The price response to volumes in long-term markets (not shown) will serve to moderate the value of a retail deposit (as would a low degree of competition in the retail funding market, which is not modeled here).

**Retail units**

The retail deposit unit raises one-period retail deposits which it on-lends to the core funding unit. It charges a markup to cover fixed costs of the retail deposit unit (eg branches).

\[
    r_d^D = (1 - \mu^D) r_d^t
\]

(20)

This has no effect on profits, or dynamics, but ensures that retail deposit rates are below retail loan rates. 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 that is an average of the short-term wholesale...
rate and the higher cost of stable funding.\footnote{21} Similarly the retail lending unit charges a fixed markup on loans, $\mu^L$, to cover fixed costs. These markups are useful to calibrate steady-state loan and deposit rates.

**Bank aggregation**

The bank’s aggregate balance sheet constraint is:

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

(21)

where $B_t^e$ is the economy’s net external debt.

### 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 investment adjustment cost parameter $\nu$ is set at 0.07 so that investment is 4.6 times as volatile as GDP in response to a technology shock to match the data. The parameter $\gamma^D$ (the interest elasticity of deposits) is set at 3. This value is consistent with the idea that deposits are not very interest elastic. In the sensitivity section we consider a range of values. The debt-sensitive risk premium parameter is set at 0.001. That value implies a real interest differential between domestic and foreign rates of 1.25% per year for the calibrated net external debt to GDP ratio of 80% of annual GDP. This is consistent with estimated values for New Zealand of 0.001 in Medina et al (2008) and 0.0014 in Munro and Sethi (2007) and empirical studies (see Laubach (2003) and Haugh et al (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 $\nu^{cfr}$ 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

\footnote{21} A fixed markdown could also be motivated by monopolistic competition in retail deposit markets as in (Gerali et al 2010) whereby differentiated deposit contracts are combined using a Dixit-Stiglitz framework. In that case the markdown would depend on the elasticity of substitution among differentiated loan contracts - the degree of the bank’s monopoly power.
minimum (see Table 3).\textsuperscript{22} The steady-state spread on multi-period funding (the term premium) is set to match the observed average of about 50bp for 5-year funding.

The markdown on the retail deposit rate and markup on the retail loan rate are calibrated to match average observed bank spreads to benchmark of 50bp and 200bp respectively (these compare to 125bp and 297-312bp used by Gerali et al (2010) for the euro area.)

We have no prior estimates for the adjustment cost parameters $\kappa^{cfr}$ and $\kappa^M$. $\kappa^M$ is calibrated at 17. This value is chosen to prevent negative new issuance in response to a 100bp spread shock. We consider a range of values in the sensitivity section. Our baseline value for $\kappa^M$ implies that a 1% rise (fall) in net new bond issuance leads to a discount (premium) of 80bp on the price of new bonds.

For a given short-run slope of the supply of long-term funding, defined by $\kappa^M$, the value of $\kappa^{cfr}$ is calibrated to 0.07 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; we assume the buffer to be fully used in a GFC-size event. This value implies that a fall of 5 percentage points in the core funding ratio incurs a cost of about 50bp on the price of new core funding.\textsuperscript{23}

All shock AR1 coefficients are set at 0.8.

### 3.4 Model properties

This section describes the changes and steady-state effects from the standard RBC model to a “benchmark” model, the introduction of a stable funding requirement, and subsequent increases in the requirement.

\textsuperscript{22} This approach fits with the observed mix of bank funding, but the marginal cost of multi-period funding is equal (defined by the maturity) for different levels of the CFR. An alternative approach would be to fix $\nu^{cfr}$ and alter the duration of bonds to match the regulatory requirement.

\textsuperscript{23} In practice, the costs are 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.
Benchmark model

The benchmark model differs from a standard open economy RBC model in four ways. First is the introduction of deposits (equation 3). 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 persistence in the model because changes in the cost of long-term funding (due to movements in the funding spread or to the “liquidity” adjustment costs on new long-term funding) feed gradually into the average cost of funds. Changes in the marginal cost of long-term funds can have large and persistent effects on the bank’s funding decisions.

Third, there is a fixed markup on retail loan rates and a fixed markdown on retail deposits rates. These are assumed to cover fixed costs and have a minor effect on dynamics.

Finally, the introduction of a stable funding requirement (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 core funding requirement in 2010.

Model with an explicit stable funding requirement

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.\(^{24}\) The steady-state effect on the retail deposit rate is 50bp (see Table 4). The steady-state effect on the average cost of funds is about 25bp. Dynamic effects of this change can be large. When the funding spread is high, the observed retail deposit spread may be higher than the observed long-term spread (equation 19, Figure 4).\(^{25}\) In our setup with a stable funding

\(^{24}\) Historically, banks have tended to shift to short-term wholesale funding when credit has expanded rapidly. This model 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 extent of the shift.

\(^{25}\) The observed rise in the retail spread may also be the result of increased competition for deposits. Increased competition would imply a smaller retail markdown, but could not account for the observed rise in the retail deposit spread above the long-term spread.
requirement, the retail deposit rate is expected to settle at a markdown of about 50bp below the average 5-year spread — so at about the benchmark rate (Figure 4).

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 impulse response graphs discussed in the next section 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 smaller 2.5bp.

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

In this type of linear model, the steady-state net external debt is fixed. In practice, as retail deposit and lending rates increase with the changes above, steady-state savings would be expected to increase and investment to fall so that the steady-state net external debt would fall. We do not capture any fall in the steady-state net debt in our linear model.\(^\text{26}\) Our calibrated deposit/GDP and net external debt/GDP ratios are held constant, implying that the supply of retail deposits is interest inelastic in the long term, and a higher stable funding ratio implies a larger share of long-term wholesale funding. The degree to which net external debt may decline is, however, uncertain. 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 global rise in savings and fall in investment might translate into a lower world real interest rate rather than a decline in net debt (globally, imbalances must sum to zero).

4 Attenuating effect on credit expansion

In the wake of the GFC, policymakers have been exploring macro-prudential policies as a means of increasing resilience in bad times and of resisting rapid credit growth, though there is less optimism that such policies will achieve the latter.\(^\text{27}\) The idea of resisting rapid credit growth is motivated, in theory, by distortions (eg. borrowers do not take into account the effect of their own borrowing on asset prices and others’ collateral constraints) and accelerator effects (eg. that arise from fire sales).

\(^\text{26}\) Non-linear models such as Bianchi and Mendoza (2010) capture such effects. In those models, even a small reduction in net debt can have large effects on model dynamics.

\(^\text{27}\) For example, see Borio (2010).
In our model, there is no explicit inefficiency associated with an expansion of credit. Implicitly, the bank underinsures against liquidity risk due to moral hazard associated with liquidity insurance provided by the lender of last resort. One could argue that the increase in deposit interest rates associated with the introduction of a stable funding requirement increases efficiency if moral hazard has led to deposit (and so loan) rates that have not reflected the stability value of deposits for the bank. That said, the aim here is to illustrate the interaction between the stable funding requirement and credit expansion rather than making a normative assessment of the requirement.

In our model, a stable funding requirement moderates credit growth for all shocks except a spread shock. We illustrate this attenuating effect by examining the responses to an investment efficiency shock and a fall in the benchmark real interest rate (Figures 5 and 6).\textsuperscript{28}

In response to a rise in investment efficiency, the household borrows to take advantage of the transitory increase in the productivity of investment by building up the capital stock and so future income.

In response to a decline in the benchmark interest rate, the household borrows while funding is cheap, to invest in the capital stock to boost future income.

To finance higher household loan demand, the bank needs to increase funding. One-period funding is always cheaper, and the bank shifts toward one-period funding (the core funding ratio falls). To avoid rising adjustment costs associated with stable funding below the desired level, the bank needs to raise stable funding as well as one-period funding.

In the benchmark model, new stable funding is raised mainly in the form of new 5-year bonds. The increase in new bond issuance drives up the marginal cost of funding in bond markets (bonds are issued at a discount) relative to one-period funding because long-term markets are less liquid than short-term markets. In the benchmark model, deposits are paid a markdown on the one-period funding cost (they are a substitute for one-period funding because the stable funding requirement does not bind),\textsuperscript{29} so the rise in long-term funding costs does not affect deposit rates directly. Deposits rise a little as the marginal utility of consumption falls (consumption rises), but by less than

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\textsuperscript{28} The same effect is seen in the response to a government spending shock or a technology shock. In the case of the latter, the effect is less prominent because much of the rise in investment is financed through the rise in income on impact, rather than a rise in debt.

The response to a technology shock is shown in Appendix B for completeness.

\textsuperscript{29} This is consistent with the observed shift toward short-term wholesale funding during periods of rapid credit growth.
loans, leading to a fall in the retail funding share, consistent with observed data. The weak deposit response means that almost all of the additional funding is raised from external wholesale funding markets, driving up the debt-sensitive risk premium which affects the cost of all funding. Despite the minor contribution of deposits to the increase in stable funding, the rising cost of bond issuance has a relatively small effect on the average cost of funds. This is because the stock of bonds accounts for only about 10% of funding, with annual bond rollover about 2% of total funding.

With a stable funding requirement, deposits are an explicit substitute for long-term funding as a source of stable funding, so deposits (about half of all funding) are paid a markdown on the marginal cost of a new bond. Therefore 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. Deposits rise strongly in response. The difference between the black solid line and blue dashed line in Figures 5 and 6 is accounted for by (i) the change in basis for the retail deposit rate, and (ii) the 5% buffer held by banks that increases the bond share of funding from 10% to 15%. The strong deposit response moderates the required increase in new bond issuance and in turn bond costs. But the higher bond share and rise in retail funding costs drive up the average cost of funds relative to the benchmark model. The rise in the deposit rate increases savings and the higher loan rate discourages investment, leading to a decline in net credit expansion (net external debt).

As the stable funding requirement is increased, bonds account for an increasing share of funding (we hold the deposit share constant, assuming that they are relatively inelastic in the long run). A given rise in credit demand drives up long-term funding spreads by less in percentage terms (on a larger bond stock), but maturing long-term funding accounts for a larger share of funding. The larger bond refinancing need dominates the smaller percentage rise in bond costs, so that the average cost of funds rises by more as the stable funding requirement is increased further moderating net credit expansion.

The path of gross loans — and so “observed” gross credit growth — is not attenuated. Net borrowing (net external debt) is gross loans less deposits. With no effect on gross loans, the fall in net (external) debt is due to the rise in deposits. Deposits are more affected than loans for two reasons. First, a rise in deposits creates utility value while a fall in loans does not. Second,

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30 This effect comes from the utility specification in our model, but may be more general. If deposits were provided by patient households, as in Gerali et al (2010), a similar effect would be present because the discounted value of deposit income to patient households would exceed the discounted cost of the same payments to the impatient household.
the deposit rate (the marginal cost of stable funding) moves by a lot more than the loan rate (a weighted average of the marginal cost of stable funding, previously contracted stable funding and new one-period funding).

We consider the effects of more liquid long-term markets and a more or less elastic deposit response in the sensitivity section.

5 Amplification of funding spread shocks

In this section, we show how the attenuating effect discussed above is dominated by an amplifying effect in the case of spread shocks.

The spread, \( m_\tau \), is the difference between the cost of funding in wholesale markets and the rollover of the benchmark interest rate (the swap rate). As shown in Figure 1, the spread is increasing in the duration of the funding, \( m \), and is counter-cyclical: it tends to be low during expansions and can be very high during periods of systemic stress.

In response to a 25bp compression of the 5-year funding spread (Figure 7), lower average funding costs lead the household to borrow more while funding is relatively cheap (loans and net debt increase), and to invest the proceeds in the capital stock to increase future income. The fall in the cost of funds affects long-term funding disproportionately because (i) long-term spreads fall by more (by \( m_\tau \) compared to \( \tau \) for one-period funding), and (ii) the spread, unlike the benchmark, cannot be hedged so is paid for the duration of the funding.

In the benchmark model, the increase in borrowing is small relative to a 25bp fall in the benchmark rate because maturing bonds account for only about 2% of total funding while a fall in the benchmark rate affects the cost of all funding. To meet higher household credit demand, the bank needs to raise funding. The bank still prefers one-period funding, which is always cheaper, but increases bond issuance while the spread is low relative to its future expected value. Deposits are paid a markdown on the cost of one-period funding, which falls only by a small amount (\( \tau \)). The small fall in the deposit rate reduces the incentive for the household to hold deposits, but that effect is dominated by fall in the marginal utility of consumption (consumption rises) as household debt service costs fall, increasing resources available for deposits. The rise in deposits and new bonds is greater than the rise in loans, so the share of stable funding (the core funding ratio) increases. The benchmark rate
rises in step with the external debt/GDP ratio but the rise is small compared to the compression of the spread, so the deposit and loan rates fall.

In the model with a stable funding requirement, the rise in net debt and GDP are amplified for two reasons. First, deposits are paid a markdown on the marginal cost of a new 5-year bond, so the deposit rate falls (with cheap long-term wholesale funding there is little incentive to bid for deposits) reducing the supply of deposits so increasing new bond issuance. The lower marginal cost of a new bond now has a larger effect on funding costs, being passed to the retail deposit base. Lower retail funding costs depress the loan rate by more, increasing the incentive to borrow. The fall in deposits is offset by a rise in new bond issuance (and the associated “liquidity” adjustment costs described in the previous section offset the amplification to some degree). Both higher loans and the fall in deposits increase net borrowing and investment in new capital.

Second, with a buffer of 5% above the minimum requirement the rollover of long-term funding is higher (despite the lower overall rollover rate, see Figure 2) so the compressed spread has a larger effect on the bank’s average funding cost, further (and persistently) depressing the loan rate and increasing the household’s incentive to borrow. As the stable funding ratio is increased, bond refinancing accounts for an increasing share of new funding so the compressed spread has a larger effect on funding costs, and in turn lending rates.

For the other model shocks, the presence of a stable funding ratio led to a rise in deposits during credit expansions; for a spread shock, the presence of a stable funding requirement leads to a fall in the deposit rate and to a decline in deposits during expansions.

The degree of amplification is increasing in both the level of the stable funding requirement and in the net external debt of the economy (exposure to the spread shock). If we were to assume that the steady-state net debt of the small open economy falls in response to rising funding costs as the stable funding requirement is increased, the scope for amplification would be moderated. If, instead, higher global savings and lower global demand translated into an equivalent fall in real benchmark interest rates (because imbalances must sum to zero globally) then the degree of amplification would not be moderated.

While the the compression of the spread is bounded (the 5-year spread can only be compressed from its steady-state value of about 50bp to zero), the spread can rise sharply during periods of systemic market stress (Figure 1).

It is useful to think of two types of funding market stress: systemic and idiosyncratic. Here our focus is on systemic stress to funding markets that is
largely unrelated to the state of the individual bank. As discussed in Acharya and Skeie (2011), systemic liquidity hoarding can lead to very high spreads for even the most creditworthy borrowers. In their setup, what matters for the probability and cost of such an event is the aggregate liquidity risk (eg. degree of leverage and/or maturity transformation) of financial institutions supplying liquidity at the wholesale level (eg. investment banks), rather than ex-ante liquidity needs for an individual bank. 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 endogenous changes in the risk characteristics of bank assets in response to the imposition of a regulatory requirement.

The response to a 100bp rise in the 5-year wholesale funding spread (Figure 9) is an inverted and scaled version of the compressed spread in Figure 7. As before, the spread shock is amplified with a stable funding requirement. The larger bond refinancing requirement amplifies the effect on funding costs because long-term funding spreads are larger, and cannot be hedged so must be paid for the duration of the funding.

The immediate response of the bank is to sharply reduce bond issuance which is very expensive. Although the market is “open” in our setup, bank profit maximisation effectively shuts down costly new bond issuance. Withdrawal from the bond market moderates the rise in funding costs by reducing the demand for bonds relative to the supply. To avoid the transitory high spread on long-term wholesale funding, the bank is willing to pay a lot for a one-period retail deposit (equation 19). The deposit response eases wholesale funding costs, but the higher interest costs on the deposit base drive up loan rates, further depressing household borrowing. The bank shifts toward one-period funding, depressing the core funding ratio by just over one percentage point for this 100bp shock (by construction to exhaust the banks’ assumed 5 percentage point buffer in response to a GFC-sized (350bp) funding spread shock). The household saves more and borrows less. The

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31 More stable funding should reduce the size of the spread shock in a Modigliani-Miller sense, but that effect may be small compared to the systemic liquidity premium. A higher ex-ante level of stable funding is not a panacea: over time funding comes due and debt must be repaid. See Aikman et al (2009) for a study of funding liquidity risk in a bank network model.

32 For example, the bank might fund more risky (higher yield) assets to offset the rise in funding costs, increasing the size/probability of a negative shock to its assets. Perotti et al (2011) examine such “risk shifting” in response to bank capital requirements.

33 In part this is because central bank liquidity operations ease liquidity pressures in short-term markets, and in part because precautionary liquidity hoarding can affect long-term markets disproportionately (Acharya and Skeie (2011)).
degree of deleveraging translates proportionately into falls in consumption, investment, capital, output and net external debt. As the stable funding requirement is increased, the higher rollover in long-term markets increases exposure to the sharp rise in the funding spread.

As the stable funding ratio increases, the higher steady-state retail deposit and loan rates could lead to a decline in the steady-state net external debt. In our calibration, we have not accounted for such a decline. This is not the right type of model to inform on the evolution of the net external position, but we illustrate in Figure 8 the effect, implicit in the model, of varying the steady-state net external debt on the depth of the recession in response to the funding spread shock in Figure 9. The height of the bars in Figure 8 at a net debt of 80% of GDP correspond to the maximum fall in GDP in Figure 9. The shift from the benchmark model to a CFR of 65% would need to be offset by a large (about 30% of GDP) fall in net external debt to get back to the original recessionary effect of the 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 (another 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, adjustment might be achieved through a decline in world real interest rates rather than shifts in external imbalances, which must sum to zero globally.

The adverse effect of the stable funding ratio in the face of a spread shock raises the question as to how such adverse effects might be moderated. In the following sections, we explore the potential roles of buffers of stable funding held by the bank above the regulatory requirement, and the role of a state-dependent requirement in mitigating adverse outcomes.

6 Policy experiments

6.1 Ex-ante buffers

In Figure 10, we consider the role of buffers held by banks above the minimum requirement that can be run down in response to a rise in the spread. In the model the buffer is reflected in a higher steady-state level of stable funding and the tightness of the regulatory constraint is adjusted to allow the bank to run down the buffer to the same 75% minimum requirement in the event of a
350bp shock (3.5 times that shown). The green dash-dot line is the same as in Figure 9 representing a bank with a 75% minimum core funding requirement and a 5% buffer. The blue dotted and red dashed lines show the responses for a buffers of 10% and 1% respectively. In the case of the 1% buffer, there is little scope to reduce 5-year issuance in response to the higher spread so the degree of deleveraging and recession is higher. With a 10% buffer, the bank can reduce 5-year issuance, avoiding the worst of the transitory funding shock, moderating macroeconomic effects.

Thus ex-ante buffers held by the bank above the minimum requirement play a useful role. They enable the bank to weather a relatively short period of market stress and moderate the degree of deleveraging driven by the high spread. Overall, however, the macroeconomic effects of the buffers are modest: outcomes are still considerably worse than the benchmark model. This is because the bank quickly runs down its buffer and finds itself at the minimum requirement and the marginal cost structure associated with that share of stable funding. For a more persistent spread shock, buffers would provide less relief than shown here. For a less-persistent spread shock, the relief provided by a larger buffer would be greater. An important benefit is the reduced dependence on central bank liquidity support.

6.2 Ex-post forbearance: a counter-cyclical overlay?

In the event of systemic market stress, it may be sensible for a regulator to ease the stable funding requirement to avoid the adverse effects of high external funding spreads on the economy (deleveraging and recession). In the extreme case of long-term funding market closure (long-term markets become stressed earlier, by more and for longer), the bank has little scope to substitute toward short-term funding without breaching the regulatory requirement.

It is useful to think about the use of a tax (price) rather than balance sheet requirement (quantity) to achieve a given degree of bank self insurance for refinancing risk. If more stable funding was achieved through a tax on non-core funding,\(^{34}\) then there would be scope for the bank to substitute toward cheaper short-term funding (plus a tax) in periods of stress rather than to continue to raise bonds subject to a “double whammy” effect of the rise

\(^{34}\) See Perotti and Suarez (2011) provide a theoretical treatment of price vs. quantity tools for liquidity regulation and (Shin and Shin 2011) for a discussion of a tax on non-core liabilities.
in the spread. While a tax-based approach might provide more flexibility during crises, it might be more difficult than a balance sheet requirement to implement in normal times, potentially being a graduated tax, subject to time-varying incentives. Here we consider a combination of the two, in the form of a central bank facility 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 over the benchmark rate.\textsuperscript{35} If such funding could be counted as core funding, its availability would undermine the incentives for the bank to raise stable funding if long-term wholesale funding spreads were 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 25-50bp on one-quarter funding.

Here we consider a central bank facility, distinct from normal liquidity operations, that could be counted toward the stable funding requirement but that would be priced at a penalty rate.\textsuperscript{36}

Figure 11 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. If the bank is allowed to substitute, without penalty,\textsuperscript{37} to cheaper one-period funding (grey dotted line), then the depth of the recession declines from about 0.6% to about 0.2%. The level of stable funding declines by 4% for this 100bp shock, or about 14% for a GFC-size shock. If substitution toward a one-period central bank facility incurs a penalty (annual) rate of 100bp (blue dashed line), then the average cost of bank funds still rises by less than the baseline model, net lending declines by less and the depth of the recession is 0.28%. At a penalty of 200bp on one-period funding (dotted orange line), the depth of the recession increases to 0.34%. This is still modest compared to the case where the only relief is from the bank’s own 5% buffer (GDP declines by 0.6%) or even a 10% buffer (GDP declines by 0.48%). While 200bp may sound like a steep penalty rate in the face of a 100bp 5-year funding spread shock, the bank still substitutes to the central bank facility because of a large penalty paid for one period is

\textsuperscript{35} In New Zealand, 50bp over the policy rate equivalent to about 25bp over the interbank benchmark rate.

\textsuperscript{36} It could also be interpreted as a shift to short-term market funding subject to regulatory charges. The idea of a penalty rate on liquidity operations to moderate moral hazard goes back to Bagehot (1873).

\textsuperscript{37} This scenario includes a small charge (in the form of the adjustment costs associated with terms in $\kappa^{cf}$) that is proportional to the extent of the breach.
better than a smaller penalty paid for 5-years. Effectively, such a facility allows the bank, during periods of stress, to run down the buffer of stable funding built up in response to the requirement. The higher level of stable funding only serves as a buffer if the buffer can be used.

Such a facility could be priced to come into play automatically in bad states, serving as a sort of release valve when the external funding markets are stressed, but fall into disuse as funding spreads decline. The point here is not to recommend what the specific penalty rate should be (the numerical values depend on the model calibration), but to illustrate the effects of such a facility. The penalty rate would put an explicit price on refinancing risk with implications for risk taking ex-ante (moral hazard).

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 decline brings into question the potential effectiveness of both buffers and forbearance: would the bank’s own buffers be run down and the facility used? In practice, the bank may be reluctant to use buffers to avoid negative signalling effects (or market pressures) in bad states or because of uncertainty regarding the persistence of the funding shock.

The design of such a 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 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

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38 Central banks can provide considerable liquidity during crises. The scope of liquidity operations is, however, limited by the quality of banks’ collateral, which is subject to escalating haircuts as credit quality declines. During the GFC, banks quickly ran out of repo-eligible collateral leading central banks to expand the range of eligible securities. Eventually such expansion risks shifting bank credit risk to the government account. 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.

39 Examples are the Term Auction Facility (TAF) in the US and New Zealand and the Longer Term Refinancing Operations (LTRO) in the euro-area.
critical in determining the contagion effects of runs that do occur.’

The amplifying effect of a stable funding requirement is similar to the amplifying effect of a capital requirement: meeting the requirement in bad times is expensive, and buffers are only useful if they can be used (Goodhart (2010)’s taxi). Therefore, counter-cyclical application of a stable funding requirement may be desirable for the same reasons that motivate a counter-cyclical capital buffer. In periods of very easy funding and compressed long-term funding spreads, a counter-cyclical “macro-prudential” overlay would require banks to build up a buffer of long-term funding while it is cheap. The discussion of a central bank facility above could be thought of as one way of implementing one phase of such an overlay.

Alternatively, a more flexible system based on charges/taxes/penalties such as the forbearance with a penalty charge discussed above or other charge-based systems (see Goodhart and Perotti (2012)) are likely have better macroeconomic properties.

Natural indicator variables for the counter-cyclical buffer are net credit growth (the degree of deleveraging) and the observed spread. The retail deposit spread may provide a better indicator of the degree of pressure on bank funding costs, incorporating factors such as the expected persistence of the spread and any offsetting effect from weakening credit demand. Thus banks’ willingness to bid up retail deposit rates precede forbearance. We leave formal analysis of a counter-cyclical buffer for further work in a model with active monetary policy since adjusting the benchmark rate provides an alternative cyclical funding cost shocks (by reducing the benchmark rate).

7 Sensitivity

A potentially important factor in the dynamics discussed here is the interest rate elasticity of deposits, the inverse of $\gamma^D$. Figure 12 shows the response to a funding spread shock for values of $\gamma^D = 0.1, 3$ (baseline) and 10. The $\gamma^D = 10$ response is very close to our baseline model where deposits are already relatively interest inelastic. As deposits become more elastic ($\gamma^D = 0.1$), the bank can avoid the worst of the funding spread shock by bidding for deposits. The deposit response allows a further fall in bond issuance, reducing marginal bond costs (via negative adjustment costs), and so retail rates and the extent of deleveraging and recession.

Are such negative adjustment costs reasonable? In the event of systemic
liquidity stress, it is unlikely that a bank can reduce bond yields sharply by reducing its volume of issuance. To prevent such a fall in costs, we set the adjustment cost parameter $\kappa^M$ to zero. This means that the slope of the 5-year funding supply curve is flat. With no relief, in terms of funding costs, deposits are offered the full marginal cost effect of the spread shock and deposits respond strongly as shown in Figure 13). With no adjustment costs, however, the model reaches the bounds of linearity: the bank engages in negative new bond issuance: it uses retail funding to invest in 5-year bonds to receive the high yield.

Similarly, when funding markets are "liquid" during periods of rapid credit growth or a "savings glut", if costs do not rise with volumes — again implying a low value for $\kappa^M$ — the response of GDP and net borrowing to the spread shock is amplified by a lot more.

For other model shocks, if the bond market is perfectly liquid ($\kappa^M = 0$), then there is no attenuation effect (see Figure 14 for the response to an investment efficiency shock). Conversely if $\kappa^M$ is large (our benchmark value is little different from $\kappa^M = 100$) then prices respond strongly to volumes and additional stable funding is mainly obtained by bidding for deposits, rather than issuing new bonds which drives up the marginal cost.

We also considered additional smoothing of consumption (by introducing habit), sticky adjustment of loan and deposit rates (as in Gerali et al (2010)) and a more modest labour supply response. None of those had material effects on the results.

8 Conclusions

This paper sets out an open economy, general equilibrium model incorporating a profit-maximising bank with disaggregated liabilities and uses this setup to explore the macroeconomic effects of a stable funding requirement. The framework employs a tractable setup for long-term funding without benchmark interest rate risk. The introduction of a stable funding requirement increases the share of long-term wholesale funding and reduces banks’ aggregate rollover risk, but increases rollover in long-term markets. Fluctuations in bond spreads can have large effects on model dynamics.

The presence of a stable funding requirement can attenuate credit expansion. In the steady state, higher funding costs associated with more long-term funding and higher retail deposit rates imply a lower steady-state net external
debt. Credit expansion is also attenuated in a dynamic sense because (i) a rise
in long-term funding volumes drives up funding costs 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 long-term wholesale funding implies
higher exposure to those rising costs because of higher rollover requirements
(despite lower aggregate rollover).

Higher exposure to long-term markets, however, increases the procyclicality of
fluctuations in funding spreads, amplifying the effects of compressed spreads
during expansions 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 they must be paid for the duration of
the funding. This is particularly important in the event of market stress
when long-term spreads can increase by a lot. Policy experiments show that
adverse effects can be moderated through suitable policy design, and suggest
that counter-cyclical policy is desirable.

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### Table 1

#### Model calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmark</th>
</tr>
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<tbody>
<tr>
<td>$\alpha$</td>
<td>capital share</td>
</tr>
<tr>
<td>$\delta$</td>
<td>depreciation rate</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>inv. elasticity of labour supply</td>
</tr>
<tr>
<td>$\varrho$</td>
<td>debt-sensitive interest premium parameter</td>
</tr>
<tr>
<td>$\upsilon$</td>
<td>investment adjustment cost parameter</td>
</tr>
<tr>
<td>$G/Y$</td>
<td>steady state government spending/GDP</td>
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<tr>
<td>$B^c/Y$</td>
<td>steady state external debt/GDP</td>
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<tr>
<td>$\beta$</td>
<td>discount rate</td>
</tr>
<tr>
<td>$D/Y$</td>
<td>steady state retail deposits/GDP</td>
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<tr>
<td>$\gamma^D$</td>
<td>interest elasticity of deposit supply</td>
</tr>
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</table>

#### Bank

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\nu^{cfr}$</td>
<td>desired core funding ratio</td>
</tr>
<tr>
<td>$\kappa^{cfr}$</td>
<td>CFR adjustment cost parameter</td>
</tr>
<tr>
<td>$\kappa^M$</td>
<td>5-year funding adjustment cost parameter</td>
</tr>
<tr>
<td>$m$</td>
<td>duration of multi-period funding (quarters)</td>
</tr>
<tr>
<td>$\bar{\tau}$</td>
<td>Term premium (mean 5yr funding spread)</td>
</tr>
<tr>
<td>$\mu^D$</td>
<td>Retail deposit markdown (annual rate)</td>
</tr>
<tr>
<td>$\mu^L$</td>
<td>Retail loan markup (annual rate)</td>
</tr>
</tbody>
</table>

#### Shock AR1 coefficients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmark</th>
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<tbody>
<tr>
<td>$\rho^A$</td>
<td>Productivity</td>
</tr>
<tr>
<td>$\rho^I$</td>
<td>Investment efficiency</td>
</tr>
<tr>
<td>$\rho^G$</td>
<td>Government spending</td>
</tr>
<tr>
<td>$\rho^s$</td>
<td>Foreign interest rate</td>
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<tr>
<td>$\rho^r$</td>
<td>Funding spread</td>
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Table 2
Moments of the model

<table>
<thead>
<tr>
<th>variable</th>
<th>New Zealand data</th>
<th>Benchmark model b/ shocks</th>
<th>Spread shock</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>1 1</td>
<td>1 1 1</td>
<td>1 1 1</td>
</tr>
<tr>
<td>Cons.</td>
<td>0.97 1.06</td>
<td>0.44 0.16</td>
<td>0.57 0.97</td>
</tr>
<tr>
<td>Inv.</td>
<td>4.60 6.35</td>
<td>4.56 16.76</td>
<td>18.97 13.78</td>
</tr>
<tr>
<td>Labour</td>
<td>0.58 0.61</td>
<td>0.44 0.49</td>
<td>0.49 0.56</td>
</tr>
<tr>
<td>Deposits</td>
<td>3.64 1.50</td>
<td>0.15 0.05</td>
<td>0.16 3.75</td>
</tr>
<tr>
<td>Loans</td>
<td>3.17 2.69</td>
<td>1.24 2.65</td>
<td>3.26 6.81</td>
</tr>
<tr>
<td>r</td>
<td>0.00 0.00</td>
<td>0.01 0.01</td>
<td>0.13 0.03</td>
</tr>
</tbody>
</table>

AR1 Coefficient

| GDP      | 0.84 0.87        | 0.851 0.98              | 0.94 0.96    | 0.98 |
| Cons.    | 0.81 0.90        | 0.98 0.99               | 0.78 0.91    | 0.93 |
| Inv.     | 0.73 0.85        | 0.88 0.88               | 0.88 0.9     | 0.94 |
| Labour   | 0.28 0.27        | 0.86 0.98               | 0.77 0.81    | 0.92 |
| Deposits | 0.86 0.77        | 0.98 0.99               | 0.79 0.995   | 0.98 |
| Loans    | 0.67 0.91        | 0.996 0.98              | 0.98 0.995   | 0.996 |
| r        | 0.85 0.90        | 0.97 0.97               | 0.77 0.994   | 0.997 |

Correlation with GDP

| GDP      | 1 1              | 1 1 1                    | 1 1 1        |
| Cons.    | 0.67 0.92        | 0.46 0.18                | 0.31 0.37    | 0.14 |
| Inv.     | 0.82 0.93        | 0.69 0.03                | -0.19 -0.19  | -0.11 |
| Labour   | 0.31 0.07        | 0.9 0.99                 | 0.84 0.57    | 0.74 |
| Deposits | 0.24 -0.14       | 0.47 0.26                | 0.33 0.92    | -0.77 |
| Loans    | -0.34 0.06       | 0.18 0.96                | 0.89 0.92    | 0.95 |
| r        | 0.50 0.79        | -0.26 0.94               | -0.26 0.89   | 0.93 |

a/ For period 1995Q1 to 2007Q2
b/ For period 2007Q2 to 2010Q4
c/ Deposits paid a markdown on the marginal cost of one-period funding.
d/ CFR 65+5% model. Deposits paid a markdown on the marginal cost of 5-year bond.
Table 3
CFR, NSFR and model calibration

<table>
<thead>
<tr>
<th>CFR</th>
<th>NSFR</th>
<th>$\nu^{cr}$</th>
<th>duration</th>
<th>deposit (%)</th>
<th>long-term wholesale (%)</th>
<th>short-term wholesale (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>65%</td>
<td>74.0%</td>
<td>58.1</td>
<td>17</td>
<td>0.47</td>
<td>0.11</td>
<td>0.42</td>
</tr>
<tr>
<td>70%</td>
<td>80.5%</td>
<td>63.7</td>
<td>17</td>
<td>0.47</td>
<td>0.17</td>
<td>0.36</td>
</tr>
<tr>
<td>80%</td>
<td>93.5%</td>
<td>74.8</td>
<td>17</td>
<td>0.47</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>90%</td>
<td>106.5%</td>
<td>86.2</td>
<td>17</td>
<td>0.47</td>
<td>0.45</td>
<td>0.08</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Benchmark Model</th>
<th>65%CFR +5% buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/Y</td>
<td>consumption/GDP</td>
<td>0.549</td>
</tr>
<tr>
<td>I/Y</td>
<td>investment/GDP</td>
<td>0.201</td>
</tr>
<tr>
<td>G/Y</td>
<td>Government spending/GDP</td>
<td>0.18</td>
</tr>
<tr>
<td>NX/Y</td>
<td>net exports/GDP</td>
<td>0.062</td>
</tr>
<tr>
<td>K/Y</td>
<td>capital/annual GDP</td>
<td>2.09</td>
</tr>
<tr>
<td>$B^e/Y$</td>
<td>Net external debt/annual GDP</td>
<td>0.8</td>
</tr>
<tr>
<td>$B^S/L$</td>
<td>one-period wholesale funding / Loans</td>
<td>0.42</td>
</tr>
<tr>
<td>$\bar{B}^M/L$</td>
<td>5-year wholesale funding / Loans</td>
<td>0.11</td>
</tr>
<tr>
<td>$D/L$</td>
<td>Retail Deposits / Loans</td>
<td>0.47</td>
</tr>
<tr>
<td>CFR</td>
<td>Stable funding / Loans</td>
<td>65%</td>
</tr>
<tr>
<td>$r$</td>
<td>benchmark interest rate (annual)</td>
<td>4.0%</td>
</tr>
<tr>
<td>$r^L$</td>
<td>retail loan rate (annual)</td>
<td>5.8%</td>
</tr>
<tr>
<td>$r^b$</td>
<td>average funding cost (annual)</td>
<td>4.1%</td>
</tr>
<tr>
<td>$r^c$</td>
<td>marginal 5-year bond (annual)</td>
<td>4.6%</td>
</tr>
<tr>
<td>$r^D$</td>
<td>retail deposit rate (annual)</td>
<td>3.7%</td>
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</table>
Table 5
Asset and Liability weights for CFR, NSFR and model

<table>
<thead>
<tr>
<th>Liabilities</th>
<th>Model</th>
<th>CFR</th>
<th>NSFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term wholesale</td>
<td>0%</td>
<td>0%</td>
<td>0-50%</td>
</tr>
<tr>
<td>Retail less than one year</td>
<td>100%</td>
<td>20-90%</td>
<td>80-90%</td>
</tr>
<tr>
<td>(mostly 90%)</td>
<td>80-90%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>greater than one year</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Long-term wholesale</td>
<td>100%</td>
<td>0%</td>
<td>0-50%</td>
</tr>
<tr>
<td>Residual maturity &lt; 6months</td>
<td>100%</td>
<td>0%</td>
<td>0-50%</td>
</tr>
<tr>
<td>Residual maturity 6-12 months</td>
<td>100%</td>
<td>50%</td>
<td>0-50%</td>
</tr>
<tr>
<td>Residual maturity &gt; 12 months</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Capital</td>
<td>N/A</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Securities and liquid assets</td>
</tr>
<tr>
<td>Loans and advances</td>
</tr>
</tbody>
</table>

Figure 1
Credit cycles and external wholesale funding costs

Note: Resident private sector credit growth. Credit growth less nominal GDP growth provides a measure of "excess" credit growth. Indicative funding spreads are USD borrowing (AA composite 5yr bond spread or USD Libor) 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)

Note: Assuming deposits are 47% of funding.

Figure 3
Bank structure
Figure 4
Bank interest rate spreads to swap

<table>
<thead>
<tr>
<th>basis points</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>-100</td>
</tr>
</tbody>
</table>

- Mortgage loan spread
- 5-year external funding spread
- 90-day external funding spread
- Deposit spread

Jan 99  Jan 01  Jan 03  Jan 05  Jan 07  Jan 09  Jan 11
Figure 5
IRF: 1% Investment efficiency shock

Note: Variables are % deviation from steady state except (i) interest rates which are percentage point deviation from the steady state level, and (ii) net external debt/GDP and the core funding ratio which are percentage point deviation from steady state ratios. For lines marked CFR XX% (+5%), the bank holds a buffer of 5pp above the required minimum ratio in steady state.
Figure 6
IRF: 25bp fall in benchmark rate

Notes: See footnote to Figure 5
Figure 7
IRF: 25bp compression of 5yr spread

Notes: See footnote to Figure 5
Figure 8
+100bp 5yr 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 9
IRF: funding market stress: +100bp 5yr spread shock

Notes: See footnote to Figure 5
Figure 10
IRF: Funding spread shock: role of buffers held by banks

Notes: See footnote to Figure 5
Figure 11
IRF: Funding spread shock: role of central bank facility

Notes: See footnote to Figure 5
Figure 12
Sensitivity to deposit elasticity ($\gamma^D$)

Notes: See footnote to Figure 5
Figure 13
Funding spread shock: no liquidity adjustment costs ($\kappa^M = 0$)

Notes: See footnote to Figure 5
Figure 14
Investment shock: variation in 5-year market adjustment costs

Notes: See footnote to Figure 5
Appendices

A  RBC model with deposits

Household optimisation problem:

\[
\max \sum_{t=1}^{\infty} \beta^{t-1} \left[ \log(C_t) + \chi_{1} D_t + \frac{1}{1 - \gamma} - \nu N_t \frac{N_t+1}{1 + \sigma} \right]
\]  \hspace{1cm} (A.1) \\
subject to: \( C_t + I_t + (1 + r_{t-1}^L) L_{t-1} = W_t N_t + R_t^K K_t + L_t + (1 + r_{t-1}^P) D_{t-1} \)

Household first order conditions

- \( C_t : \) \( \beta \frac{U_t'}{U_{t+1}'} = \Lambda_{t+1} \hspace{1cm} (A.2) \)
- \( L_t : \) \( 1 = E_t \left\{ \Lambda_t \left(1 + r_t^L \right) \right\} \hspace{1cm} (A.3) \)
- \( D_t : \) \( 1 = \nu \sigma_{t+1} \left(1 + r_t^D \right) \hspace{1cm} (A.4) \)
- \( N_t : \) \( \nu N_t = W_t \hspace{1cm} (A.5) \)

Firm optimisation problem:

\[
\max \sum_{t=1}^{\infty} \beta^{t-1} (Y_t - W_t N_t - R_t^K K_t) \]  \hspace{1cm} (A.6) \\
subject to: (i) Cobb-Douglas production: \( Y_t = \eta_t \alpha_t N_t^{1-\alpha} \)

(ii) Law of motion of capital: \( K_{t+1} = (1 - \delta) K_t + \eta_t S \left( \frac{1}{1 - \gamma} \right) I_t \)

Firm first order conditions:

- \( N_t : \) \( W_t = (1 - \alpha) \frac{Y_t}{N_t} \hspace{1cm} (A.7) \)
- \( I_t : \) \( 1 = Q_t^K \left\{ S \left( \frac{1}{1 - \gamma} \right) + \frac{1}{1 - \gamma} \right\} - E_t \left\{ \Lambda_t + Q_t^R S \left( \frac{1}{1 - \gamma} \right) \right\} \hspace{1cm} (A.8) \)
- \( K_t : \) \( Q_t^K = E_t \left\{ \Lambda_t (1 - \delta) + Q_t^K (1 - \delta) \right\} \hspace{1cm} (A.9) \)

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

Resource constraint: \( Y_t = C_t + I_t + N X_t \)

National accounts identity: \( Y_t = C_t + I_t + \bar{G} + N X_t \)

Balance of payments. \( (B_t^e \text{ is a liability. The bank is foreign owned.}) \)

\[
\begin{align*}
B_t^e &= B_t^S + \bar{B}_t^M = L_t - D_t \\
B_t^c &= (1 + r_{t-1}^L) L_{t-1} - (1 + r_{t-1}^D) D_{t-1} - N X_t
\end{align*}
\]  \hspace{1cm} (A.10)
B  IRF: 1% Technology shock

Notes: See footnote to Figure 5