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## A macroprudential stable funding requirement and monetary policy in a small open economy*

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## Abstract

The Basel III net stable funding requirement, scheduled for adoption in 2018, requires banks to use a minimum share of long-term wholesale funding and deposits to fund their assets. This paper introduces a stable funding requirement (SFR) into a small open economy DSGE model featuring a banking sector with richly-specified liabilities. We estimate the model for New Zealand, where a similar requirement was adopted in 2010, and evaluate the implications of an SFR for monetary policy trade-offs. Altering the steady-state SFR does not materially affect the transmission of most structural shocks to the real economy and hence has little effect on the optimised monetary policy rules. However, a higher steady-state SFR level amplifies the effects of bank funding shocks, adding to macroeconomic volatility and worsening monetary policy trade-offs conditional on these shocks. We find that this volatility can be moderated if optimal monetary or prudential policy responds to credit growth.

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## Non-technical Summary

The Basel III net stable funding requirement, scheduled for adoption in 2018, requires banks to use a minimum share of stable funding, in the form of long-term wholesale funding and deposits, to fund their assets. We introduce a stable funding requirement (SFR) into a small open economy model featuring a banking sector with richly-specified liabilities; deposits as well as short-term and long-term bonds. The SFR regulates the proportion of loans financed by the 'stable' component of the bank's liabilities. The model is estimated for New Zealand, where a similar policy, the Core Funding Requirement, was adopted in 2010. A distinctive feature of the model is that it allows banks to issue short-term and long-term home currency-denominated debt overseas, in order to make loans in the small open economy.

We evaluate how the presence of the SFR alters monetary policy trade-offs between the volatility in inflation, and volatility in other variables such as output, interest rates and exchange rates. A higher SFR raises the share of long term foreign bonds on the banks' balance-sheet and hence increases the economy's exposure to shocks to the interest rate spread on long-term foreign debt. This in turn leads to macroeconomic volatility and hence worsens monetary policy trade-offs. However, since the SFR mainly affects the composition of bank funding rather than the cost, the SFR does not affect the transmission of other macroeconomic disturbances that do not affect the bank funding spread. Since bank funding spread disturbances have a negligible influence on the business cycle, the operation of monetary policy is little changed in the presence of the SFR. The additional macroeconomic volatility generated by the presence of the SFR can be diminished and monetary policy trade-offs can be improved if: (i) the central bank raises the interest rate to react systematically to increases in measures of credit growth in the economy and (ii) the SFR policy is varied over time to respond to credit growth.

# 1 Introduction

Central banks act as lenders of last resort to prevent liquidity pressures from becoming solvency problems. Liquidity provision by central banks, however, can lead to the problem of moral hazard. The availability of public liquidity reduces the incentive for banks to raise relatively expensive 'stable' funding such as retail deposits and long-term bonds, and leads banks to underinsure against refinancing risk. In periods when credit has grown rapidly, retail deposits have tended to grow more slowly, and banks have shifted toward less stable funding from short-term wholesale markets. 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 through funding from other financial institutions. In response to the systemic liquidity stress experienced during the recent global financial crisis, extensive liquidity support was provided to banks, reinforcing incentives for moral hazard. Hence, stronger liquidity regulation has been proposed to increase banks' self-insurance against liquidity risk.

The Basel III liquidity regulations, scheduled to come into force in 2018, include a net stable funding ratio (NSFR) that requires banks to raise a share of funding from more stable retail deposits and long-term wholesale funding, rather than short-term wholesale funding.[1] In this paper, we introduce the stable funding requirement into a fairly standard small open economy (SOE) general equilibrium model with nominal rigidities and then examine how the new prudential policy alters monetary policy trade-offs. Central to our modelling strategy is the design of a banking sector with disaggregated liabilities: retail deposits, and short-term and long-term wholesale funding. The stable funding requirement regulates the proportion of deposits and long-term liabilities on the bank's balance-sheet and a deviation from the required proportion of stable funding is subject to a penalty function.[2] We consider the case of New Zealand, a country that in 2010 adopted a liquidity policy that is similar to the Basel III proposals. In particular, the New Zealand policy includes a core funding requirement that is similar in spirit to the Basel III NSFR and maturity mismatch ratios.[3]

[1] In addition to the NSFR, the Basel III liquidity requirements include a liquidity coverage ratio.

[2] A previous working paper version of this paper, Bloor, Craigie, and Munro (2012), studied a similar banking sector set-up involving long-term debt and deposits in a calibrated real business cycle model. We thank Chris Bloor and Rebecca Craigie for contributions in the early stages of the project.

[3] The Basel III NSFR is defined as the ratio of available stable funding to required stable funding (see www.bis.org/publ/bcbs189.pdf). The New Zealand Core Funding Ratio is defined as the ratio of stable funding to loans and advances (see www.rbnz.govt.nz/regulationandsupervision/banks/prudentialrequirements/4664431.html). Although the definitions differ in details and in calibration, they are broadly equivalent. The numerator includes deposits, long-term wholesale funding and equity, and excludes short-term wholesale funding. The denominator includes loans, which are typically illiquid, and excludes more liquid assets.

We show the history of the core funding ratio in New Zealand in Panel (a) of Figure 1. Before the regulation was put in place in April 2010, New Zealand banks used stable funding due to internal risk management considerations or implicit requirements imposed by creditors and rating agencies. New Zealand's experience with the stable funding requirement, provides us with a time series on the stable funding ratio, which, along with other key macroeconomic and financial series, facilitates the estimation of the SOE model. We estimate the model with Bayesian methods using quarterly data over 1998 to 2014.

The estimated model is used to evaluate the implications of the macroprudential instrument for monetary policy trade-offs. We examine its effects on loss-minimising policy rules derived from varied specifications of the central bank's monetary policy loss function. Taking into account the influence of all the estimated structural shocks, the presence of the stable funding requirement makes little difference to loss-minimising monetary policy rules. However the picture is starkly different in the case of the shock to the funding spread which affects long-term financing.

It is well known that credit spreads are compressed during booms and expand during recessions.[4] As shown in Panel (b) of Figure 1, New Zealand dollar wholesale funding spreads were low during the build-up to the global financial crisis and rose sharply during the crisis. Long-term funding spreads can be important for the commercial banks because they are larger and more variable than short-term spreads.[5] The spread component must be carried for the duration of the funding because it cannot be hedged, unlike the benchmark interest rate. A stable funding requirement that increases the share of long-term funding in banks' balance sheets increases the banks' exposure to shocks in the long-term bond market. This feature of the policy instrument makes it an amplifier of the transmission of spread shocks; if a higher proportion of banks' liabilities are held in long-term bonds when the spreads on these bonds rise, the upward pressure on domestic lending rates is stronger and hence economic activity contracts further. The macroeconomic volatility that is generated by this mechanism worsens monetary policy trade-offs. We find that this additional volatility can be moderated if monetary and prudential policy respond directly to credit growth.[6] Since the current account in our model reflects movements in domestic (net) credit, systematic monetary and prudential responses to the current account can also reduce macroeconomic volatility and improve monetary policy trade-offs.

[4] See *e.g.* Christiano, Rostagno, and Motto (2014) for the US experience.

[5] See Acharya and Skeie (2011) for a theoretical discussion.

[6] Our results regarding the moderation of losses when monetary policy leans against the wind is along the lines of Quint and Rabanal (2014) and Lambertini, Mendicino, and Punzi (2013). However, they focus on loan-to-value ratios as the prudential instrument, and their metric for evaluating optimal policy is maximisation of households' welfare.

The paper lies at the interface of several strands of the literature. The first is the theoretical literature that explicitly incorporates financial regulation into macroeconomic models, *e.g.* Gertler, Kiyotaki, and Queralto (2012), Roger and Vlcek (2011), Gertler and Karadi (2011), de Walque, Pierrard, and Rouabah (2010), Covas and Fujita (2010), Van den Heuvel (2008), and Goodfriend and McCallum (2007).[7] The focus on the stable funding requirement, which has not received previous attention, distinguishes our contribution to the theoretical literature. On the other hand, the empirical dimension of this paper links it to the literature on DSGE models of financial intermediation estimated with Bayesian methods on US or Euro-area data, as in *e.g.* Christiano, Rostagno, and Motto (2014), Jermann and Quadrini (2012) or Gerali, Neri, Sessa, and Signoretti (2010). The consumer-bank interaction in our model is closest to that of Gerali, Neri, Sessa, and Signoretti (2010) who estimate a New Keynesian model with banks on Euro-area data. However, they focus on different macroprudential instruments, namely restrictions on loan-to-value ratios and bank capital holdings. Furthermore, since we fit our model to New Zealand, a very open economy, we introduce international trade in goods and financial assets. The banking sector in our model interacts with a real economy which has much in common with the empirical small open economy models of Adolfson et al. (2007) and Bergin (2003).[8]

The estimated model forms the foundation for our policy analysis where we examine the implications of the stable funding requirement for monetary policy trade-offs. This dimension of the paper links it to a growing DSGE model-based literature focussing on optimal monetary and prudential policy. This literature has hitherto focused on the interactions between monetary policy and loan-to-value ratios or capital requirements, *e.g.* Quint and Rabanal (2014), Gelain and Ilbas (2014), Angelini, Neri, and Panetta (2014), Lambertini, Mendicino, and Punzi (2013), and Angeloni and Faia (2013). In contrast, we assess how monetary policy trade-offs are altered due to the presence of a stable funding requirement. To this end, we use a monetary policy loss function specified in terms of macroeconomic volatilities akin to those used in Angelini, Neri, and Panetta (2014) and Gelain and Ilbas (2014), and study optimised policy rules that minimise the policy loss function.[9]

Finally, the modelling strategy for the introduction of long-term wholesale funding, which is one of the key target variables of the stable funding requirement, links the paper to the literature

[7] A vast literature in finance also studies financial frictions and regulation in smaller scale models, often set in partial equilibrium, solved by non-linear techniques. See Angelini, Neri, and Panetta (2014) for a review of this literature.

[8] Alpanda, Cateau, and Meh (2014) also consider macroprudential policy in the context of a calibrated small open economy model for Canada. While their focus is on loan-to-value ratios and capital requirements, the structure of the real economy is quite similar to ours.

[9] On the other hand, Quint and Rabanal (2014) and Lambertini, Mendicino, and Punzi (2013) use household welfare criteria derived from model-specific utility functions. Angeloni and Faia (2013) employ separate criteria based on welfare as well as volatilities.

on 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. While this approach is suitable to model fixed-rate financial assets, it can imply a large degree of interest rate risk and associated valuation effects. In our model, multi-period bonds pay a floating rate coupon on the benchmark component to eliminate benchmark interest rate risk, in addition to a fixed-rate spread that cannot be hedged. The introduction of an additional state variable enables us to model the cost structure of bank funding more realistically, implicitly accounting for the fact that modern banks use interest rate swaps to hedge benchmark interest rate risk.[10]

The rest of the paper is set out as follows. In Section 2 we introduce the stable funding requirement in an SOE model for New Zealand and Section 3 describes the estimation results. The implications of the stable funding requirement for monetary policy trade-offs are explored in Section 4. Section 5 concludes.

# 2 A Small Open Economy Model with a Stable Funding Requirement

## 2.1 Preliminaries

The model involves two countries, the home country being infinitesimally small when compared to the foreign country. The home country, henceforth referred to as the small open economy (SOE), is populated by a continuum of identical households indexed by $h \in [0, 1]$, a continuum of firms indexed by $f \in [0, 1]$ and a continuum of banks indexed by $\iota \in [0, 1]$ . The firms are owned by the households while the banks are owned by the foreign economy, the latter assumption in accordance with the New Zealand experience. In the spirit of Justiniano and Preston (2010) the foreign economy, *i.e.* the rest of the world, is represented by a three-equation closed-economy New Keynesian model which is not impacted by the SOE. The non-banking segment of the model is fairly standard, along the lines of the empirical SOE models of Adolfson et al. (2007) and Bergin (2003). Hence this section focusses on the bank and its interactions with the real economy. The more conventional behavioural equations are presented in the appendix and the derivation of the model is available on request.

Variables representing nominal quantities are presented in upper case and when they are deflated by the consumption price index ($P_c$), they are instead presented in lower case. Net

[10] A different strategy for modelling long-term debt in the context of fixed- and variable-rate mortgages, is considered by Brzoza-Brzezina, Gelain, and Kolasa (2014). See the references therein for the literature studying long-term debt in the housing market.

nominal interest rates and net inflation are also presented in lower case. Typically, a variable $z$ in the non-stochastic steady-state is presented as $\bar{z}$. A logarithmic deviation of the variable relative to its steady-state in period $t$ is represented as $\hat{z}_t \equiv \frac{\partial z_t}{\bar{z}} = \log \frac{z_t}{\bar{z}}$. In addition, we also use the notation $\tilde{z}_t \equiv \partial z_t$ for net interest rates and inflation in the log-linearised model to indicate percentage deviations in absolute terms. $\mathbb{E}$ represents the conditional expectations operator. The typical stochastic shock process $e$ embedded in the model is assigned the law of motion $\log e_t = (1 - \rho_e) \log \bar{e} + \rho_e \log e_{t-1} + \sigma_e \eta_t$ where $\eta_t \sim$ i.i.d. $\mathbb{N}(0,\ 1)$, $\sigma_e > 0$ and $\rho_e \in (0,\ 1)$.

## 2.2 Households

The generic household $h$ has a consumption basket which is a CES aggregate of domestic and imported goods.[11] The household's utility function is separable between consumption $(c_h)$ adjusted for external habit-formation, and labour $(n_h)$. In contrast to the standard New Keynesian literature, the household holds deposits $(d_h)$ at the bank that enter the utility function as a third argument, again separably from consumption and labour. The presence of deposits in the household's preferences is motivated by their liquidity value in lowering transaction costs.[12]

Bank deposits yield a net nominal return of $r^D$ to the household. The banking sector also influences the income side of household's budget constraint by issuing loans $(\ell_h)$ at the net nominal rate $r^L$. The remaining features of the household's role in the SOE are very standard. The household buys the investment good $(i_h)$ at the nominal price $P_i$ to augment the physical capital stock $(k_h)$. Like the consumption good, the investment good is a CES aggregate of domestic output and imports. The investment good is however allowed to have a different import-share from consumption. Installed capital is rented out to the firm at the real net rate of $r_c^k$. As in Erceg, Henderson, and Levin (2000), each household is a monopolistic supplier of specialised labour $(n_h)$. Perfectly competitive 'employment agencies' aggregate the specialised labour-varieties from the households into a homogenous labour input $(n)$ using a CES technology and sell it to the firm. The employment agencies return to the household a labour-type specific nominal wage $(W_h)$. We also introduce nominal wage rigidities by stipulating that it is costly *à la* Rotemberg (1982) to change wages. Finally, the household also receives nominal dividends $(\Omega_h)$ through its ownership of firms. The household maximises its expected utility subject to the law of motion for the endogenous discount factor in Equation (2), period budget constraint in Equation (3), capital accumulation constraint in Equation (4), and its labour-variety specific

[11] See Section A in the appendix for details on functional form.

[12] de Walque, Pierrard, and Rouabah (2010) adopt a similar strategy in their DSGE model with a banking sector. Deposits could instead be created by introducing patient and impatient households with the former depositing funds in the bank and the latter demanding loans as in *e.g.* Gerali et al. (2010). The deposits-in-the-utility function approach provides tractability.

demand constraint in Equation (5).

$$\max_{\substack{d_{h,t},\ \ell_{h,t},\ n_{h,t},\\ c_{h,t},\ k_{h,t},\ i_{h,t},\ W_{h,t}}} \mathbb{E}_0 \sum_{t=0}^{\infty} \varepsilon_{\beta,t}\xi_t \left[ \log\left(c_{h,t} - \gamma_c c_{t-1}\right) + \frac{d_{h,t}^{1-\omega_d}}{1-\omega_d} - \frac{n_{h,t}^{1+\omega_n}}{1+\omega_n} \right] \tag{1}$$

$$\text{subject to } \frac{\xi_{t+1}}{\xi_t} \equiv \beta_t = \left(1 + \beta_c \log c_t\right)^{-1}, \tag{2}$$

$$c_{h,t} + \frac{P_{i,t}}{P_{c,t}} i_{h,t} + d_{h,t} + \frac{\left(1 + r_{t-1}^{L}\right)}{\left(1 + \pi_{c,t}\right)} \ell_{h,t-1} = \frac{W_{h,t}}{P_{c,t}} n_{h,t} - \frac{\chi_w}{2} \left( \frac{W_{h,t}}{W_{h,t-1}\left(1 + \bar{\pi}_c\right)} - 1 \right)^2 \frac{W_t}{P_{c,t}} n_t$$

$$+ r_{c,t}^{k} k_{h,t-1} + \frac{\left(1 + r_{t-1}^{D}\right)}{\left(1 + \pi_{c,t}\right)} d_{h,t-1} + \ell_{h,t} + \frac{\Omega_{h,t}}{P_{c,t}}, \tag{3}$$

$$i_{h,t}\varepsilon_{i,t} \left[ 1 - \phi\left( \frac{i_{h,t}}{i_{h,t-1}} \right) \right] + \left(1 - \delta_k\right) k_{h,t-1} = k_{h,t}, \tag{4}$$

$$\text{and } n_{h,t} = n_t \left( \frac{W_{h,t}}{W_t} \right)^{-\vartheta_{n,t}}, \tag{5}$$

$$\text{where } \gamma_c \in [0,1),\ \xi_0 = 1,\ \beta_c > 0\ \omega_n,\ \omega_d > 0,\ \delta_k \in [0,1],$$

$$\phi(1) = \phi'(1) = 0,\ \phi''(1) > 0,\ \vartheta_{n,t} > 1.$$

$W$ is a nominal wage-index for the aggregated unit of labour used by the firms and $1 + \pi_{c,t} \equiv P_{c,t}/P_{c,t-1}$ is the gross CPI inflation. $\xi$ is a time-varying endogenous discount factor which is a decreasing function of average consumption. This device is a technical assumption to ensure that the incomplete financial markets model is stationary and is drawn from Ferrero, Gertler, and Svensson (2007).

In a symmetric equilibrium, the optimality conditions for loans ($\ell$) and deposits ($d$) are respectively:

$$1 = \mathbb{E}_t \Lambda_{t,t+1} \frac{\left(1 + r_t^L\right)}{\left(1 + \pi_{c,t+1}\right)}, \tag{6}$$

and

$$\frac{d_t^{-\omega_d}}{\lambda_t} + \mathbb{E}_t \Lambda_{t,t+1} \frac{\left(1 + r_t^D\right)}{\left(1 + \pi_{c,t+1}\right)} = 1. \tag{7}$$

$\lambda$ is the marginal utility of consumption and $\Lambda_{t,t+1} \equiv \lambda_{t+1}/\lambda_t$ is the stochastic discount factor. Equation (6) is a conventional Euler equation, the only difference being that the return on loans, and not the policy rate determines the intertemporal substitution of consumption. The optimality condition in Equation (7) equates the sum of the current marginal utility gain from deposits, $d_t^{-\omega_d}$ and the discounted expected utility gain from gross deposit returns $\mathbb{E}_t \Lambda_{t,t+1} \left(1 + r_t^D\right) / \left(1 + \pi_{c,t+1}\right)$ to the cost of foregone consumption. Consequently, in periods when the marginal utility of consumption is high, the household lowers deposit holdings. Observe that the elasticity of deposits to the real return is decreasing in the parameter $\omega_d$. From the perspective of bank funding, a high value for $\omega_d$ allows deposits to be very sticky and hence a more stable source of funding for the bank.[13] The other first order conditions are standard and are presented in the appendix.

### 2.3 Bank

It is useful to think of the representative bank as being comprised of three interconnected units:

1. The retail banking units are the interface of the bank with the households and they operate in a monopolistically competitive market as in Gerali et al. (2010). The retail deposit and loan units incur adjustment costs in adjusting interest rates. In the long-run, the deposit unit raises deposits at rates which are lower than the internal value of funds, while the loan unit lends available funds to the households at a mark-up over the internal cost.

2. The stable funding unit combines retail deposits and multi-period bonds into stable funding, which is lent to the aggregate funding unit

3. The aggregate funding unit combines stable funding and 1-period wholesale funding, subject to a stable funding requirement.

The bank is owned by foreign residents, a stylised feature of the model adapted to the New Zealand economy where most of the banks are owned by Australian parent institutions (see *e.g.* Bollard, 2004 and Hull, 2002). For this reason, bank profits are not rebated to domestic households, but are instead transferred overseas. We start with the description of the aggregate funding unit on which the stable funding requirement, henceforth referred to as the SFR, is imposed.

#### 2.3.1 Aggregate Funding Unit and the SFR

The aggregate funding unit of the representative bank $\iota$ combines stable funding $B^{sf}$ with short-term wholesale funding $B$ to fund a floating-rate loan of nominal value $L$ to households. Although set up as a one-period loan, the interest rate structure – and therefore the implicit duration – of the loan reflects the duration of the bank's funding.[14] The average nominal interest cost of the stable funding unit is given by $r^{sf}$ while $r$ is the rate paid on one-period wholesale

[13] Later in the estimation results presented in Section 3, we confirm that this is indeed the case for New Zealand as the estimate of $\omega_d$ exceeds 100.

[14] The bank on-lends the funds to the retail loan unit at cost. The average rate on many overlapping loans priced at the marginal cost is the same as the rate on a representative loan priced at the bank's average cost of funds. Since the retail units smooth lending rates, changes in the bank's marginal costs are only gradually passed through to lending rates.

funding. The aggregate funding unit chooses the (CPI-deflated) quantities of stable funding and short-term wholesale funding that maximise the discounted sum of real cash flows subject to the balance sheet constraint:

$$\max_{b^{sf}_{\iota,t},\, b_{\iota,t}} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda^{af}_{0,t} \left[ \begin{array}{c} b^{sf}_{\iota,t} + b_{\iota,t} + \frac{(1+r^{\ell}_{t-1})}{(1+\pi_{c,t})}\ell_{\iota,t-1} - \ell_{\iota,t} - \frac{\left(1+r^{sf}_{t-1}\right)}{(1+\pi_{c,t})}b^{sf}_{\iota,t-1} - \frac{(1+r_{t-1})}{(1+\pi_{c,t})}b_{\iota,t-1} \\ -\frac{b^{sf}_{t-1}}{(1+\pi_{c,t})}\Upsilon\left(\frac{b^{sf}_{\iota,t-1}}{\ell_{\iota,t-1}}\right) \end{array} \right] \tag{8}$$

subject to

$$\ell_{\iota,t} = b^{sf}_{\iota,t} + b_{\iota,t}, \tag{9}$$

where $\Lambda^{af}$ is the discount factor of the aggregate funding unit. The SFR enters the cash-flow problem through an adjustment cost function. The bank incurs a cost $\Upsilon()$ when the stable funding to loans ratio deviates from the requirement of $\nu^{sfr}$. In particular:

$$\Upsilon\left(\frac{b^{sf}_{\iota,t}}{\ell_{\iota,t}}\right) = \gamma_0 + \gamma_1\left(\frac{b^{sf}_{\iota,t}}{\ell_{\iota,t}} - \nu^{sfr}_t\right) + \frac{\gamma_2}{2}\left(\frac{b^{sf}_{\iota,t}}{\ell_{\iota,t}} - \nu^{sfr}_t\right)^2. \tag{10}$$

The cost function $\Upsilon()$ is adapted from the capacity utilisation literature, *e.g.* Greenwood, Hercowitz, and Huffman (1988), and has a linear as well as quadratic component. The objective is to obtain a non-zero steady-state value for the first derivative of the cost, so that there exist wedges between the interest rates in the long run, as observed in the sample means in the data.[15] While it is natural to think of the stable funding ratio as being a result of explicit, external regulation, it may also reflect banks' internal risk management or pressure from creditors. In the absence of the adjustment penalty, the bank would seek to fund only from short-term markets.

The optimality condition for short-term wholesale funding ($b$) defines the spread between the nominal internal loan rate $r^{\ell}$ received from the lending unit and the nominal benchmark rate $r$ paid for short-term wholesale funding:

$$r^{\ell}_t - r_t = -\left(\frac{b^{sf}_t}{\ell_t}\right)^2 \Upsilon'\left(\frac{b^{sf}_t}{\ell_t}\right). \tag{11}$$

The left hand side of Equation (11) is the additional profit from an additional unit of lending funded with short-term wholesale borrowing and the right hand side is the cost of deviating from the SFR. Combining the above condition with the optimality condition for stable funding (not exhibited) yields the spread between the nominal rate $r^{sf}$ paid to the stable funding unit

[15] In Section 3 on the empirical implementation of the model, we set $\gamma_0$ to zero while $\gamma_1$ is pinned down by the steady-state restrictions. $\gamma_2$ is estimated.

and the cost of short-term wholesale funding:

$$r_t^{sf} - r_t = -\frac{b_t^{sf}}{\ell_t}\Upsilon'\left(\frac{b_t^{sf}}{\ell_t}\right). \tag{12}$$

Here, the benefit of substituting one unit of cheaper short-term wholesale funding for one unit of stable funding, $r^{sf} - r$ is equated with the cost of deviating from the SFR. Combining the two equilibrium conditions above, we can express the average cost of loanable funds as a weighted average of the short-term wholesale rate and the average rate paid for stable funding, with the weight determined by the stable funding to loans ratio:

$$r_t^{\ell} = \left(\frac{b_t^{sf}}{\ell_t}\right) r_t^{sf} + \left(1 - \frac{b_t^{sf}}{\ell_t}\right) r_t. \tag{13}$$

In addition to stable- and short-term funding, the aggregate funding unit has access to foreign currency one-period bonds, which are in zero net-supply. The no-arbitrage condition between home and foreign currency one-period bonds is given by:

$$\mathbb{E}_t \Lambda_{t,t+1}^{af} \frac{(1+r_t)}{(1+\pi_{c,t+1})} = \mathbb{E}_t \Lambda_{t,t+1}^{af} \frac{ner_t}{ner_{t+1}} \frac{(1+r_t^*)}{(1+\pi_{c,t+1})}, \tag{14}$$

where $ner$ is the foreign currency price of one unit of home currency so that a rise indicates an appreciation of the home currency. This uncovered interest parity condition establishes that the *ex ante* returns on home and foreign bonds, converted to the same currency, yield the same expected value. In its log-linearised form, the condition implies that a rise in the home interest rate over the foreign rate will immediately appreciate the home currency, which is then expected to depreciate to offset the higher home interest return.

### 2.3.2 The Stable Funding Unit

The SFR stipulates that the bank funds a share of their assets through either deposits or multi-period bonds. While the stickiness of deposit demand makes deposits a stable source of bank funding, multi-period bonds are stable in the sense that only a fixed proportion mature in each period and hence they are associated with less funding liquidity risk than 1-period market funding. We depart from the standard one-period debt structure commonly incorporated in DSGE models (see *e.g.* Adolfson et al., 2007), and introduce multi-period bonds into the bank's balance-sheet. In particular, long-term debt enters the optimisation programme of the stable funding unit of the bank that produces stable funding $B^{sf}$ by combining its stock of unmatured multi-period bonds $S^m$ available in the current period with one-period retail deposits. The stable funding unit then lends the funds to the aggregate funding unit at the net average cost of stable funding, $r^{sf}$. In CPI-deflated terms, the balance sheet constraint of the stable funding unit is given by:

$$d_t + s_t^m = b_t^{sf}. \tag{15}$$

**Modelling Multi-period Debt and Interest** Our strategy to model long-term debt is based on that of Woodford (2001) who incorporates a perpetuity-structure into an otherwise conventional DSGE model to study fixed-rate long-term government debt. However, long-term debt with fixed returns, would expose the bank to a large degree of interest-rate risk, unless all the bank's assets and liabilities have matched duration. To eliminate benchmark interest-rate risk, we augment Woodford's framework by including two distinct components into the return on long-term bonds: a floating rate benchmark and a fixed spread.[16] In every period, new bonds $B^m$ of fixed duration $d^m$ are sold to non-residents at the net floating benchmark rate ($r$) and an additional funding spread that is fixed at the time of issuance and hence cannot be hedged.[17] The bond repayments are split into two parts: firstly fixed principal repayments and the fixed spread, and secondly, floating rate coupon payments. As in Woodford (2001), the principal and the fixed spread are repaid in an infinite number of installments decaying geometrically at the rate $\delta^m \in [0, 1)$, starting from the next period. The second floating rate coupon component is paid on the stock of outstanding bonds. The degree of funding liquidity risk is determined by the maturity of the bond which is a function of the rate of decay $\delta^m$. If $Q_t$ is the fixed payment related to principal and the fixed spread on long-term debt raised in period $t$, then total repayments on debt raised in period $t$ are scheduled as follows:

$$\begin{array}{ll}
\text{In period } t+1: & (Q_t + r_t)\, B_t^m \\
\text{In period } t+2: & \delta^m (Q_t + r_{t+1})\, B_t^m \\
\text{In period } t+3: & (\delta^m)^2 (Q_t + r_{t+2})\, B_t^m \\
\text{In period } t+4: & (\delta^m)^3 (Q_t + r_{t+3})\, B_t^m \\
\quad\quad . & \quad\quad . \\
\quad\quad . & \quad\quad . \\
\quad\quad . & \quad\quad . \\
\text{In period } t+z: & (\delta^m)^{z-1} (Q_t + r_{t+z-1})\, B_t^m
\end{array}$$

[16] Other variants of Woodford's perpetuity set-up have been used by Alpanda, Cateau, and Meh (2014) and Benes and Lees (2010).

[17] Fixed-coupon payments (or receipts) are assumed to be swapped to floating-coupon payments (or receipts) at the one-period benchmark rate combined with a fixed spread.

Note that $Q_t B_t^m$ covers the principal repayment $(1-\delta^m) B_t^m$ and the fixed spread $\tau_t^m B_t^m$ component of interest payments, so that $Q_t = 1-\delta^m+\tau_t^m$.[18] The sum of repayments of the principal in addition to the fixed spread on all past wholesale funding due in period $t$ (excluding floating interest payments) is

$$J_{t-1} = \sum_{z=1}^{\infty} (\delta^m)^{z-1} \left(Q_{t-z} B_{t-z}^m\right), \tag{16}$$

which can expressed in recursive form as:

$$J_t = \delta^m J_{t-1} + Q_t B_t^m. \tag{17}$$

The book value of the principal declines at the rate $\delta^m$ so that the law of motion of the stock of unmatured bonds $S^m$ is given by:

$$S_t^m = \delta^m S_{t-1}^m + B_t^m. \tag{18}$$

The spread $\tau^m$ on the cost of long-term wholesale funding is modelled as an exogenous AR(1) process. The exogeneity of the funding spread is well suited to the case of banks from the small open economy accessing external wholesale bank funding markets. Such spreads may be driven by aggregate risk, rather than idiosyncratic bank-specific risk.

**Optimal Deposit and Bonds Funding** In period $t$, the stable funding unit receives gross interest returns to funds lent to the aggregate funding unit in the previous period, 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 $J_{t-1} + r_{t-1} S_{t-1}^m$ and is subject to adjustment costs if it expands funding from less-liquid long-term markets. We present the optimisation problem of the representative stable funding unit in terms of CPI-deflated quantities:

$$\max_{\substack{b_{\iota,t}^{sf},\, d_{\iota,t},\, b_{\iota,t}^m \\ j_{\iota,t},\, s_{\iota,t}^m}} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{sf} \left[ \begin{array}{c} b_{\iota,t}^m + d_{\iota,t} + \frac{\left(1+r_{t-1}^{sf}\right)}{(1+\pi_{c,t})} b_{\iota,t-1}^{sf} - b_{\iota,t}^{sf} - \frac{j_{\iota,t-1}}{(1+\pi_{c,t})} - r_{t-1} \frac{s_{\iota,t-1}^m}{(1+\pi_{c,t})} \\ - \frac{\left(1+r_{t-1}^d\right)}{(1+\pi_{c,t})} d_{\iota,t-1} - \frac{\kappa^m}{2} \left( \frac{b_{\iota,t}^m}{b_{\iota,t-1}^m} - 1 \right)^2 b_t^m \end{array} \right] \tag{19}$$

[18] The duration $d^m$ of the funding is the expected present value $(PV)$ of repayments discounted at the rate of return on stable funding. Defining $R^{sf} = 1 + r^{sf}$, $\mathbb{E}_t PV_{t+z} = (\delta^m)^{z-1} (Q_t + \mathbb{E}_t r_{t+z}) \left( R_t^{sf} \mathbb{E}_t R_{t+1}^{sf} ... \mathbb{E}_t R_{t+z-1}^{sf} \right)^{-1}$ weighted by the time-to-maturity: $d^m = \sum_{z=1}^{\infty} z \mathbb{E}_t PV_{t+z} / \sum_{z=1}^{\infty} \mathbb{E}_t PV_{t+z}$. In the non-stochastic steady-state, $\bar{d}^m = \bar{R}^{sf} / \left(\bar{R}^{sf} - \delta^m\right)$.

subject to

$$j_{\iota,t} = \delta^m \frac{j_{\iota,t-1}}{(1+\pi_{c,t})} + Q_t b^m_{\iota,t}, \tag{20}$$

$$\text{and } s^m_{\iota,t} = \delta^m \frac{s^m_{\iota,t-1}}{(1+\pi_{c,t})} + b^m_{\iota,t}, \tag{21}$$

where $\Lambda^{sf}$ is the discount factor of the stable funding unit. The law of motion constraints in Equations (20) and (21) are associated with the lagrange multipliers $\Psi$ and $\Phi$ respectively. The term involving $\kappa^m \geqslant 0$ is a quadratic adjustment cost associated with changing the stock of nominal bonds raised. Implicitly, such a cost may represent higher marketing costs or commitment issues related to debt repayment. Since the bank borrows in home currency, such costs may relate not only to net issuance in foreign debt markets, but also to markets for hedging foreign currency exposure. In effect, this feature captures 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, *i.e.* new issuance exceeds maturing debt, then the bank sells the bonds at a discount.

In a symmetric equilibrium, the first order conditions stable funding $\left(b^{sf}\right)$, deposits $(d)$, multi-period bonds $(b^m)$, repayments on past borrowing $(j)$, and the stock of bonds $(s^m)$ are respectively:

$$1 = \mathbb{E}_t \Lambda^{sf}_{t,t+1} \frac{\left(1+r^{sf}_t\right)}{(1+\pi_{c,t+1})}, \tag{22}$$

$$1 = \mathbb{E}_t \Lambda^{sf}_{t,t+1} \frac{\left(1+r^{d}_t\right)}{(1+\pi_{c,t+1})}, \tag{23}$$

$$1 = \Psi_t Q_t + \Phi_t + \frac{b^m_t}{b^m_{t-1}} \kappa^m \left(\frac{b^m_t}{b^m_{t-1}} - 1\right) - \mathbb{E}_t \Lambda^{sf}_{t,t+1} \left(\frac{b^m_{t+1}}{b^m_t}\right)^2 \kappa^m \left(\frac{b^m_{t+1}}{b^m_t} - 1\right), \tag{24}$$

$$\Psi_t = \mathbb{E}_t \frac{\Lambda^{sf}_{t,t+1}}{(1+\pi_{c,t+1})} \left(1 + \delta^m \Psi_{t+1}\right), \tag{25}$$

$$\text{and } \Phi_t = \mathbb{E}_t \frac{\Lambda^{sf}_{t,t+1}}{(1+\pi_{c,t+1})} \left(r_t + \delta^m \Phi_{t+1}\right). \tag{26}$$

Equations (22) and (23) are standard asset pricing conditions which equalise the returns for stable funding $r^{sf}$ and the one-period retail deposits $r^d$. The optimality condition for multi-period bonds in Equation (24) associates the price of a new bond to the sum of the present value of expected future fixed payments $\Psi Q$ and the present value of expected floating rate payments, $\Phi$. In addition, observe that in the presence of positive adjustment costs $(\kappa^m > 0)$, increasing bond holdings decreases the proceeds from issuing the bond in the current period.

However, in the ensuing period the costs are lower, augmenting the value of the bond. The first order condition for fixed payments in Equation (25) pins down the dynamics of the associated marginal profit. A unit decrease in $j$ increases the profit of the bank in the current period by $\Psi_t$ while reducing the future profit by raising repayments in the next period by a factor of $1+\delta^m\Psi_{t+1}$. In present value terms, the two coincide in equilibrium. Analogously, the optimality condition for unmatured bonds $s^m$ in Equation (26) determines the path of marginal profits $\Phi$ from making floating rate repayments.

**Combining new bonds with previously contracted bonds** Deposits and new bonds are raised at the marginal cost of stable funding and unmatured bonds are paid at the benchmark rate, in addition to the previously contracted spreads. The proceeds of bonds are lent to the aggregate funding unit at the average cost of stable funding:

$$\frac{\left(1+r_{t-1}^{sf}\right)}{(1+\pi_{c,t})}b_{t-1}^{sf} = \frac{(1+r_{t-1}^{d})}{(1+\pi_{c,t})}d_{t-1} + \frac{j_{t-1}}{(1+\pi_{c,t})} + \frac{(r_{t-1}+\delta^m)}{(1+\pi_{c,t})}s_{t-1}^{m} + \frac{\kappa^m}{2}\left(\frac{b_t^m}{b_{t-1}^m}-1\right)^2 b_t^m \quad (27)$$

### 2.3.3 The Retail Units

Following Gerali et al. (2010), we model market power in retail loan and deposit banking markets using a Dixit-Stiglitz framework. We assume that (real) units of loans and deposits bought by households are a composite CES basket of differentiated financial products, with elasticities of substitution $\vartheta^L$ and $\vartheta^D$ respectively. The degree of monopolistic competition in the retail banking markets is increasing in these elasticities. Each household seeks to minimise repayments over the range of individual contracts. Aggregating over symmetric households, the aggregate loan and deposit demand faced by the bank are given by:

$$\ell_{\iota,t} = \ell_t\left(\frac{r_{\iota,t}^L}{r_t^L}\right)^{-\vartheta_t^L} \text{ and } d_{\iota,t} = d_t\left(\frac{r_{\iota,t}^D}{r_t^D}\right)^{-\vartheta_t^D}. \quad (28)$$

The retail lending unit receives funds from the aggregate funding unit and lends the funds to households. In adjusting the loan rate, it incurs quadratic adjustment costs, increasing in $\kappa^L > 0$. The lending unit of the bank $\iota$ maximises expected profits subject to the demand function given above:

$$\max_{r_{\iota,t}^L} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^L \left[\left(r_{\iota,t-1}^L - r_{t-1}^{\ell}\right)\ell_{\iota,t-1} - \frac{\kappa^L}{2}\left(\frac{r_{\iota,t}^L}{r_{\iota,t-1}^L}-1\right)^2 r_t^L \ell_t\right] \text{ subject to } \ell_{\iota,t} = \left(\frac{r_{\iota,t}^L}{r_t^L}\right)^{-\vartheta_t^L}\ell_t, \quad (29)$$

where $\Lambda^L$ is the associated discount factor. In a symmetric equilibrium, the first order condition is given by:

$$\frac{r_t^L}{r_{t-1}^L}\kappa^L\left(\frac{r_t^L}{r_{t-1}^L}-1\right)=\mathbb{E}_t\Lambda_{t,t+1}^L\left[\left(\frac{r_{t+1}^L}{r_t^L}\right)^2\frac{\ell_{t+1}}{\ell_t}\kappa^L\left(\frac{r_{t+1}^L}{r_t^L}-1\right)-\vartheta_t^L\left(\frac{r_t^L-r_t^\ell}{r_t^L}\right)+1\right]. \quad (30)$$

The lending rate exhibits Phillips-curve type dynamics, changing only gradually in response to the change in the cost of funds $r^\ell$. Note that in the absence of adjustment costs, the retail rate is set as a markup over the internal loan rate, *i.e.* $r_t^L = r_t^\ell\vartheta_t^L/\left(\vartheta_t^L-1\right)$.

The retail deposit unit faces a optimisation problem similar to that of the lending unit and sets the wedge between the deposit rate $r^D$ and the internal value $r^d$. The corresponding optimality condition is:

$$\kappa^D\frac{r_t^D}{r_{t-1}^D}\left(\frac{r_t^D}{r_{t-1}^D}-1\right)=\mathbb{E}_t\Lambda_{t,t+1}^D\left[\kappa^D\left(\frac{r_{t+1}^D}{r_t^D}\right)^2\frac{d_{t+1}}{d_t}\left(\frac{r_{t+1}^L}{r_t^L}-1\right)-\vartheta_t^D\left(\frac{r_t^d-r_t^D}{r_t^d}\right)+1\right], \quad (31)$$

where $\Lambda^D$ is the discount factor of the retail deposit unit. In the absence of adjustment costs, optimality requires that $r_t^d = r_t^D\vartheta_t^D/\left(\vartheta_t^D-1\right)$ so that the markup over the internal value is less than unity.

### 2.4 Firms

The production structure of the SOE is similar to that of Adolfson et al. (2007) and Bergin (2003). Hence we offer only a verbal description here and list the equations in the appendix. There are three categories of intermediate firms: domestic, importing and exporting firms. The domestic firms produce a differentiated good using capital and labour inputs in a Cobb-Douglas combination. They sell the intermediate good to a final good producer who uses a continuum of these intermediate goods in production. The importing firms, in turn, transform a homogenous good, bought in the world market, into a differentiated import good, which they sell to the households. The exporting firms buy the domestic final good and differentiate it to become a monopolistic supplier of its specific product in the world market. We impose quadratic price adjustment costs *à la* Rotemberg (1982) in the profit maximisation problems for domestic, import and export sales. In addition, prices are assumed to be sticky in the currency of the buyer so that exchange rate passthrough is imperfect both for import and export prices. The final consumption and investment goods are CES aggregates of the aggregated domestic good and the aggregated imported good.

### 2.5 Balance of Payments

Aggregating the constraints of the household, the firm and the bank, we arrive at the balance of payments (in nominal terms) of the SOE:

$$\begin{aligned}\frac{P_{x,t}}{ner_t}y_{x,t} - \frac{P_t^*}{ner_t}\left(c_{m,t} + i_{m,t}\right) + P_{c,t}b_t^m + P_{c,t}b_t \quad &= \quad P_{c,t-1}j_{t-1} + r_{t-1}P_{c,t-1}s_{t-1}^m \\ &\quad + \left(1 + r_{t-1}\right)P_{c,t-1}b_{t-1} + \Omega_t^B + AC_t^B.\end{aligned} \tag{32}$$

The first two terms reflect the trade balance: the excess of the revenue from exporting volumes ($y_x$) at the price ($P_x$) over the expenditure on consumption imports ($c_m$) and investment imports ($i_m$) at the acquisition cost ($P^*$) of the foreign good. The next two terms represent the country's net external debt: the nominal value of outstanding bills and bonds borrowed from non-residents. The right hand side reflects the previous period's net external debt in addition to payments that accrue to the foreign economy including interest and principal repayments, bank profits $\left(\Omega^B\right)$, and quadratic adjustment costs $\left(AC^B\right)$. Recall that the banks are owned by foreign residents and consequently the profits are transferred overseas.

The foreign economy is modelled as the canonical closed-economy New Keynesian model with an Euler equation, Phillips curve and a monetary policy rule jointly determining the dynamics of output, inflation and the nominal interest rate.

### 2.6 Policy

The model is closed by specifying monetary and prudential policy. The monetary policy authority sets the benchmark nominal interest rate according to a Taylor-type rule. The nominal interest rate is influenced by past interest rates and also responds to the expected CPI inflation rate. $r_R \in [0, 1)$ measures the inertia in the policy rate and $r_\pi > 1$ is the elasticity of the policy rate to inflation while $r_y$ governs the reaction to output:

$$\frac{1 + r_t}{1 + \bar{r}} = \left(\frac{1 + r_{t-1}}{1 + \bar{r}}\right)^{r_R} \left(\frac{1 + \mathbb{E}_t\pi_{c,t+1}}{1 + \bar{\pi}_c}\right)^{(1-r_R)r_\pi} \left(\frac{y_t}{\bar{y}}\right)^{(1-r_R)r_y} \exp\varepsilon_{mp,t}. \tag{33}$$

$\varepsilon_{mp}$ is the unsystematic, exogenous component in the conduct of monetary policy and is modelled as an AR(1) process. Finally, prudential policy is defined by a rule-based approach to setting the SFR. The SFR is influenced by past SFR settings and also may respond to the funding spread.[19] $\rho_{sfr} \in [0, 1)$ measures the inertia in the SFR setting and $\nu_\tau$ is the elasticity of the

[19] We also estimated variants of the model where the spread systematically responds to output. However, the coefficient was close to zero and statistically insignificant.

SFR to the funding spread, while $\sigma_{sfr}\eta_{sfr,t}$ may be interpreted as the unsystematic, exogenous component of variation in the SFR:

$$\nu_t^{sfr} = \left(\nu_{t-1}^{sfr}\right)^{\rho_{sfr}} \left(\tau_t^m\right)^{(1-\rho_{sfr})\nu_\tau} \exp\left(\sigma_{sfr}\eta_{sfr,t}\right). \tag{34}$$

# 3 Estimation

Several papers in the literature have presented DSGE models estimated on New Zealand data (see *e.g.* Kamber et al., 2015, Justiniano and Preston, 2010, Kam et al., 2009 and Lubik and Schorfheide, 2007). Since these models exclude an explicit role for financial intermediation, we will now take the SOE model to the data in order to pin down the financial parameters and shocks that are important for the policy analysis that follows in Section 4. The model estimation as well as the ensuing optimal policy analysis in Section 4, are implemented in the Matlab-based toolbox Dynare Version 4.4.2 (see Adjemian et al., 2011).

## 3.1 Data and methodology

The SOE model is estimated employing 15 quarterly macroeconomic time series for New Zealand. We use per capita growth rates of output, consumption, investment, deposits, loans and bond holdings. The remaining data series are: CPI inflation, export price inflation, import price inflation, real wage inflation, the 90-day bank bill rate (which closely tracks the policy rate), retail deposit rate, retail loan rates, the 5-year funding spread and finally, the observed stable funding ratio.

The observed measure of the stable funding ratio we use is the ratio of the sum of retail deposits and wholesale funding with a residual maturity greater than a year, to total funding. We abstract from bank capital and from liquid assets which on average account for roughly 10% of assets in New Zealand. Since these components of the balance sheet are not explicitly modelled in our framework, the calibration of the model SFR is adjusted to account for this omission.

Although the Reserve Bank of New Zealand only imposed the stable funding requirement in April 2010, New Zealand banks have previously used stable funding due to internal risk management strategy or implicit requirements imposed by creditors and rating agencies. Hence, the starting date for this time-series, predates the official requirement imposed in 2010. The availability of data for the spread limits the start-date of the sample to 1998.Q4 and the dataset ends in 2014.Q3. Table 1 presents a more detailed description of the data.

We apply the Bayesian estimation methodology discussed by An and Schorfheide (2007). The Bayesian approach combines prior knowledge about structural parameters with information in the data as embodied by the likelihood function. The combination of the prior and the likelihood function yields posterior distributions for the structural parameters, which are then used for inference. The appendix provides further technical details on the estimation methodology in Section B.

### 3.2 Priors

An overview of the priors used for the structural parameters are documented in Table 2 and those for the shocks are detailed in Table 3. Since we have no previous estimates for the banking sector parameters for New Zealand, the priors that we use are very diffuse. The retail deposit and loan adjustment parameters $\left(\kappa^D,\ \kappa^L\right)$ are given Normal priors centered at 5 which span the range of estimates of Gerali et al. (2010) for the Euro-area. The curvature parameter $(\gamma_2)$ for the stable funding adjustment cost function is given a similar prior as the retail interest rate cost parameters. The interest rate elasticity of the demand for deposits $(\omega_d)$ is given a Normal prior centred at 50 but is allowed to cover a wide range of values with the standard deviation being set very high at 200. The Normal priors that we use for the bond adjustment cost parameter $(\kappa^m)$ and the elasticity of the stable funding requirement to the spread $(\nu_\tau)$ are given low means at 0.1 and 0 respectively, along with a unit variance. The investment adjustment cost parameter $(\phi_i)$ is given a Normal prior centered at 5, which spans the region covered by similar cost parameters estimated in the literature.[20] The cost and indexation parameters for price and wage adjustment are given Normal priors centered at the posterior estimates of Kamber et al. (2015). Other real-economy parameters such as those pertaining to the monetary policy rule, habit persistence and shock persistence and volatility are given priors similar to those of Kamber et al. (2015).

A subset of the structural parameters are given dogmatic priors at calibrated values. Most of these parameters are crucial for the model's steady-state while others are fixed as there is insufficient information in the dataset to achieve identification. The share of capital in production is fixed at 0.30 and the depreciation of the capital stock is given a value of 0.025. The price and wage markups are set at 1.1. We rely on the estimates for the New Zealand economy presented in Kamber et al. (2015) to fix the inverse of the Frisch elasticity of labour at 1.34 and the import- and export-demand price elasticities at 0.52 and 0.81 respectively. These

[20] Smets and Wouters (2007) find an estimate of 5.7 for the United States and Adolfson et al. (2007) estimate the parameter to be 7.7 for the Euro-area.

values are close to the standard parameterisations used in the literature. We rely on New Zealand national accounts data to calibrate the long-run share of exogenous (government) spending in output at 0.14 and the import-shares of consumption and investment and the export-to-output ratio at 0.20, 0.68 and 0.31 respectively. The foreign-economy parameters are given the same values as those of the domestic-economy analogues.

Following Gerali et al. (2010), the parameters that pertain to the banking sector are calibrated to match observed interest rates, spreads and funding shares. In our case, they are chosen to match properties of the New Zealand banking system. The steady-state loan markup is set at 1.4 to match the average 200 basis point spread between the effective mortgage rate and the model-implied average cost of funds. Similarly, the deposit markdown is calibrated at 0.76 to match the average 75 basis point spread between the model-implied average cost of stable funding and the 6-month retail deposit rate. The steady-state bond spread is set at 0.0038, equivalent to 150 basis points per year. The steady-state ratio of deposits to (annual) output is set at 0.8. The ratio of net external debt to (annual) output is 0.7. The average duration of new bonds is set at 5 years to match the average maturity of New Zealand bank wholesale funding with a residual maturity of more than a year. The steady-state SFR is set at 0.54, to match the sample average ratio of the sum of deposits and bonds to loans.

### 3.3 Posteriors

Tables 2 and 3 also present the moments of the marginal posterior distributions of the estimated parameters. The estimates of the parameters related to the banking sector are of particular interest as we have no previous empirical evidence of their magnitudes. The parameter $\gamma_2$ that governs the curvature of the SFR penalty function is estimated at 5.02 which is quite close to the prior mean that is imposed. The data is more informative about the other financial parameters. The preference parameter $\omega_d$ that influences the volatility of deposit demand is very high at 112, implying that the deposits are extremely sticky. The retail loan and deposit rate adjustment cost parameters are estimated at about 9.5 and 7.3 respectively which are not far from the estimates of Gerali et al. (2010) about 10 and 4 for the Euro-area. The bond adjustment cost parameter $\kappa^m$ is statistically insignificant as is the response $(\upsilon_\tau)$ of the SFR to the funding spread. The investment adjustment cost parameter is estimated at about 4.8 which is similar to the value obtained by Smets and Wouters (2007) for the United States. The remaining real-economy parameters pertaining to nominal rigidities and the monetary policy reaction function are in the ballpark of the corresponding estimates for New Zealand presented in Kamber et al. (2015).[21]

The transmission channels of three structural disturbances – the funding spread shock, monetary policy shock and the SFR shock – are crucial for the policy analysis that we pursue in the remainder of the paper. Since the interaction between the monetary and macroprudential instruments are closely linked to the business cycle dynamics triggered by these disturbances, we defer the discussion of the estimated impulse responses to the next section. There we focus on the dynamics from the baseline estimation results and how the transmission channels are affected when we alter model features. A discussion of the dynamics triggered by the wider array of shocks that we have employed in the estimation, is available on request.

# 4 The SFR and Monetary Policy Trade-offs

We now consider the interaction between the SFR and monetary policy. First, in Section 4.1, we describe the monetary policy loss functions that form the basis for the analysis to follow. We then examine the design of optimal monetary and cyclical SFR policy, from the perspective of the monetary policy loss function, within the class of the empirical rules defined by Equations (33) and (34). For each of these exercises, we set all the non-policy structural parameters at the posterior mode. In Section 4.2, we restrict our attention to the effect of changes in the steady-state SFR level on monetary policy trade-offs. In Section 4.3, we ask whether extending the monetary policy rule with financial indicators can improve outcomes. Finally, in Section 4.4, we examine if varying the SFR instrument in response to financial variables can improve monetary policy trade-offs.

## 4.1 Monetary Policy Loss Functions

A crucial ingredient in our policy analysis is the specification of the loss function of the monetary policy authority. Our choice of the loss function is motivated by two concerns. Firstly, the functional form of the loss function should be consistent with the Policy Targets Agreement (PTA 2012) between the Governor of the RBNZ and the Minister of Finance, which states the goals of the RBNZ as:

> The policy target shall be to keep future CPI inflation outcomes [near target] on average over the medium term... In pursuing its price stability objective, the Bank

[21] We evaluate the overall empirical fit of the model in Section B. The volatilities and persistence observed in the data are generally in line with the predictions of the model.

> shall ... have regard to the efficiency and soundness of the financial system, ... and seek to avoid unnecessary instability in output, interest rates and the exchange rate.

Secondly, we need to ensure that the optimal policy parameters delivered by the selected loss function, given the model, are empirically plausible.

We consider four specifications of the loss functions: three from the literature, and one that is specific to the estimated model. We first consider two 'standard' loss functions used in Justiniano and Preston (2010):

$$\mathcal{L}_t = \tilde{\pi}_t^2 + \tilde{r}_t^2 \tag{35}$$

$$\mathcal{L}_t = \tilde{\pi}_t^2 + 0.5\hat{y}_t^2 + \tilde{r}_t^2 \tag{36}$$

Loss functions such as these above have also been used in the recent macroprudential literature, *e.g.* Angelini, Neri, and Panetta (2014) and Gelain and Ilbas (2014). The third loss function we consider is from Kam, Lees, and Liu (2009) who estimate a monetary policy loss function for New Zealand of the form:

$$\mathcal{L}_t = \tilde{\pi}_t^2 + 0.41\hat{y}_t^2 + 0.61\Delta\tilde{r}_t^2 + 0.005\widehat{rer}_t^2, \tag{37}$$

where $rer$ is the CPI-based real exchange rate.

None of these loss functions from the literature deliver optimal monetary policy parameters that are in the neighbourhood of the estimated rule. Therefore we also consider a loss function which is more consistent with the estimated model. In particular, we assume that the estimated policy rule is optimal, given the model and given central bank preferences, and then use the estimated reaction function to make inferences about the loss function parameters.[22] As a first step, we choose a generalised form of the loss function:

$$\mathcal{L}_t = \tilde{\pi}_t^2 + \Theta_{\mathbb{X}}.\mathbb{X}_t^2, \tag{38}$$

where the welfare loss ($\mathcal{L}$) is increasing in deviations from the primary inflation target, and in deviations in one or more candidate variables in the vector $\mathbb{X}$. $\mathbb{X}$ represents a subset of the following variables: the level or change in the output-gap, the policy interest rate, and the real

[22] There are multiple ways to specifying an appropriate welfare loss function and a more detailed treatment of this issue is beyond the scope of our paper. Several studies recover loss function parameters from observed policy behaviour, conditional on the model and on the assumption that observed central bank behaviour is optimal. In the DSGE literature, Kam, Lees, and Liu (2009) back out loss function parameters for Australia, Canada and New Zealand using a small open economy New Keynesian model based on Gali and Monacelli (2005), while Dennis (2006) and Ilbas (2012) implement a similar exercise for the United States.

exchange rate, all of which are associated with the subsidiary objectives of the Reserve Bank stated in the PTA (2012). $\Theta_{\mathbb{X}}$ is a vector of the weights attached to the candidate variables in the loss function. Recall that the monetary policy reaction function that we have specified in the model is of the (log-linear) form:

$$\tilde{r}_t = r_R \tilde{r}_{t-1} + (1 - r_R)\left(r_\pi \mathbb{E}_t \tilde{\pi}_{c,t+1} + r_y \hat{y}_t\right). \tag{39}$$

For each combination of candidate variables in the loss function, we solve for the optimal policy rule coefficients $\left\{r_R^{opt},\ r_\pi^{opt},\ r_y^{opt}\right\}$. The results are reported in Table 4. For the simplest possible loss function that includes only the primary inflation target ($\Theta_{\mathbb{X}} = 0$), optimal policy coefficients are far from their estimated analogues; the optimal inflation response is almost 90 compared to about 2 in the estimated monetary policy rule.

We add the additional candidate loss function variables one at a time, and calculate the optimal policy rule coefficients for a grid of loss function weights, $\Theta_{\mathbb{X}}$. For each functional specification, we report the weights that yield optimal policy rule parameters closest to the estimated rule. This final step is in line with our second objective to ensure that the optimal policy rule is empirically plausible. None of the one- or two-variable loss function specifications considered (not exhibited in Table 4), deliver optimal policy coefficients that span the estimated rule. The loss function that delivers optimal policy coefficients closest to the estimated rule, includes the volatility of inflation, the interest rate, and changes in the real exchange rate:

$$\mathcal{L}_t = \tilde{\pi}_t^2 + 1.74\tilde{r}_t^2 + 0.55\Delta\widehat{rer}_t^2. \tag{40}$$

The optimal policy coefficients for this specification of the loss function are given by $r_R^{opt} = 0.86$, $r_\pi^{opt} = 1.95$ and $r_y^{opt} = 0.035$. With this model-specific loss function, we can carry out policy experiments in the neighborhood of the estimated policy rule.

### 4.2 The steady-state SFR level and monetary policy trade-offs

The Reserve Bank of New Zealand introduced the core funding ratio, the analogue of the model SFR, in April 2010 and set it at 65% the then-existing average level of stable funding. Subsequently the requirement increased in two steps from 65% to 70% in July 2011, and then adjusted upward to 75% in January 2013. How does raising the required SFR level alter optimal monetary policy rules? Our benchmark is the estimated model, for which the steady-state model SFR is set at the sample mean. In this experiment, we proceed in three steps: (i) we remove the mild historical procyclicality of the requirement, setting $\upsilon_{\tau} = 0$, (ii) we turn off SFR shocks, and then (iii) we raise the steady-state SFR.

The changes in losses under these alternative specifications are reported in the Panel (a) of Table 5 for the four loss functions described in the previous section. Historically, the stable funding ratio has tended to be weakly pro-cyclical. The posterior mode of $\nu_{\tau}$, the SFR response to the spread in Equation (34), is 0.41. In other words, the SFR has tended to rise a little when funding spreads have been high, and to ease when they have been low. Reflecting both the change in policy, and the statistical insignificance of the estimated value, we first set $\nu_{\tau}$ to zero. As shown in the second row of Panel (a) in Table 5, eliminating that mild pro-cyclical application of the SFR hardly affects monetary policy trade-offs, for all the loss functions we consider. The next row shows the effect of abstracting from the cyclical variation in the SFR, setting $\nu_t^{sfr}$ to zero. Removing the variation in the cyclical component reduces the monetary policy losses further, but the reduction is again small, reflecting the modest role of SFR shocks for loss function variables.

We then raise the steady-state SFR $\left(\bar{\nu}^{sfr}\right)$ from 0.54 to 0.63, then to 0.73, and finally to 0.83, which are the adjusted model equivalents of the changes made to the requirement since its introduction. Observe that raising the steady-state level of the model SFR worsens monetary policy trade-offs materially, as compared to the experiments presented in the second and third rows.

We demonstrate that the worsening trade-offs at higher levels of the steady-state SFR are mainly associated with funding spread shocks. This can be seen from the bottom half of Panel (a) in Table 5, where we present results for the same set of experiments, but for the counter-factual scenario when spread shocks are deactivated. In that case, monetary policy trade-offs are largely invariant to the steady-state SFR level. The worsening trade-offs caused by spread shocks at higher steady-state SFR levels is better understood by examining the related features of the model environment and the impulse response functions generated by the spread shock.

The funding spread shock directly affects the demand function for one source of stable funding, namely long-term bonds, in Equation (24). On the other hand, the proportion of long-term bonds in the bank's balance sheet affects the bank's average cost of funds through Equation (13). The analogues of these two optimality conditions in the first-order approximation of the model are given as:

$$\Delta \hat{b}_t^m = \mathbb{E}_t \frac{1}{1+\bar{r}^d} \Delta \hat{b}_{t+1}^m - \frac{1}{\kappa^m \left(\bar{Q}+\bar{r}\right)} \left(\bar{Q}\hat{\Psi}_t + \bar{r}\hat{\Phi}_t + \tilde{\tau}_t^m\right), \tag{41}$$

$$\text{and } \tilde{r}_t^{\ell} = \bar{\nu}^{sfr}\tilde{r}_t^{sf} + \left(1 - \bar{\nu}^{sfr}\right)\tilde{r}_t + \bar{\tau}^m \bar{\nu}^{sfr}\left(\hat{b}_t^{sf} - \hat{\ell}_t\right). \tag{42}$$

When the steady-state SFR $\left(\bar{\nu}^{sfr}\right)$ is high, the proportion of long-term bonds $(b^m)$ in the bank's balance sheet is raised. In this setting, an increase in the funding spread $(\tau^m)$ on the bonds pushes up the cost of stable funding $\left(r^{sf}\right)$ and in turn the internal loan rate $\left(r^{\ell}\right)$. The increase in the internal cost of funds increases the price of retail loans and depresses economic activity. This mechanism is key in generating the dynamics presented in Figure 2 which demonstrates how the economy responds to an exogenous widening of the funding spread for the different levels of the steady-state SFR.

The baseline estimated impulse responses with the steady-state SFR set at the sample mean of 0.54 are presented in solid black lines. As the steady-state share of stable funding rises, the economy's long-term bond holdings rise and it becomes increasingly sensitive to the rise in the bond spread. Accordingly, demand falls by more, leading to a larger monetary policy loosening, and through interest arbitrage, a larger exchange rate depreciation. Intuitively, a higher SFR amplifies the effect of spread shocks because the requirement is expensive to maintain in bad times when funding spreads rise.[23] The additional volatility emanating from a higher steady-state SFR contributes to higher monetary policy losses. If spread shocks were the main source of business cycle fluctuations, monetary policy losses would be minimised if the long-run SFR is easened.

In stark contrast, the changes in the real-economy dynamics generated by varying the steady-state SFR are almost imperceptible, when we consider other shocks. For example, in Figure 3, in response to an exogenous rise in the policy interest rate, households withdraw deposits to smooth consumption, and banks replace that source of stable funding from a very liquid bond market. Recall that the posterior estimate of the bond adjustment cost parameter $\kappa_m$ is statistically not different from zero and hence banks can increase bond-issuance almost costlessly. The real economy is hardly affected by changes in the steady-state SFR since it only alters the composition of bank funding; only the financial variables are affected.

We have seen that monetary policy trade-offs worsen as the steady-state level of the SFR is raised. What does this imply for the implementation of monetary policy? We examine the results for the model-specific loss function in Equation (40) that allows us to examine changes in the neighborhood of the estimated rule. As the steady-state level of the SFR is increased, we can see from Panel (b) of Table 5 that there is very little change in the parameterisation of the

[23] The role of the SFR as an amplifier of spread shocks is reminiscent of the role of bank capital requirements as an amplifier of business cycles (see *e.g.* Blum and Hellwig, 1995). Capital requirements are pro-cyclical since they raise the cost of issuing equity during downturns.

monetary policy rule $\left\{r_r^{opt},\ r_\pi^{opt},\ r_y^{opt}\right\}$. Although the sensitivity of the economy to the cost of stable funding increases with the tightening steady-state SFR, and monetary policy trade-offs worsen, the implementation of monetary policy is hardly affected. The optimal coefficients remain in the vicinity of the estimated values. We will continue to restrict our attention to the model-specific loss function in Equation (40) in Sections 4.3 and 4.4.

### 4.3 Extending the monetary policy rule with financial variables

In this section, we ask whether augmenting the monetary policy rule with financial variables can improve trade-offs while keeping the prudential instrument unchanged. In the next set of experiments, we include an additional term, $r_x x_t$, in the monetary policy reaction function:

$$\tilde{r}_t = r_R \tilde{r}_{t-1} + (1 - r_R)\left(r_\pi \mathbb{E}_t \tilde{\pi}_{c,t+1} + r_y \hat{y}_t + r_x x_t\right), \tag{43}$$

where $x$ is an additional financial indicator variable. We start with the funding spread and sequentially also consider measures of credit and asset prices. Given the model-specific loss function in Equation (40), we optimise over all monetary policy rule parameters, in the case of each indicator variable. The baseline for all these experiments is the estimated model, but with $\nu_\tau$ set to zero, to eliminate the mild pro-cyclicality of the SFR estimated in the data. The results are summarised in Panel (a) of Table 6.

Losses decline relative to the baseline case, when monetary policy responds systematically to two indicators related to credit growth; loan growth and the current account. Macroeconomic volatility is reduced (relative to baseline) when monetary policy is tightened in response to a rise in loan growth or to a larger current account deficit. In our model, the excess of loans disbursed by the bank over the deposits it receives is financed by borrowing from international financial markets. The current account is defined as the change in net foreign assets, *i.e.* the negative of the change in net foreign debt, and is effectively the excess of deposit growth over gross loan growth. The improvement in monetary policy trade-offs by responding to credit growth is in the spirit of the results of Quint and Rabanal (2014) and Lambertini, Mendicino, and Punzi (2013), who find support for a monetary response of 'leaning against the wind' to credit growth, in the context of a closed-economy. The similarity in results is particularly striking since these papers examine welfare-optimal policy in models of housing, and hence the objectives they pursue are considerably different from ours.

The optimal coefficients on loan growth (0.38) and the current account (−0.06) are substantially larger than those for other indicators. For example, the optimal monetary policy response to the spread is negative but very small at $-0.0003$, despite the fact that the presence of the SFR amplifies the economy's response to disturbances to the funding spread. The other conventional monetary policy reaction function parameters do not materially change when alternative indicators are used. In the next section, we abstract from indicator variables in the monetary policy rule, and instead introduce additional indicators in the macroprudential policy rule, to evaluate monetary policy trade-offs. We continue to focus on the model-specific loss function.

### 4.4 Can a time-varying SFR policy improve monetary policy tradeoffs?

In May 2013, a memorandum of understanding between the Reserve Bank and the Minister of Finance introduced the idea that the core funding requirement, the policy analogue of our model SFR, can be varied over time in response to the build-up of systemic risk.[24] That is, banks may be required to increase the share of stable funding when systemic risk rises. To understand the impact of a time-varying SFR on the economy, we first demonstrate the dynamics triggered by the exogenous component of the SFR rule in Equation (34) in the estimated model. Figure 4 presents the response to an exogenous increase of 5 percentage points in the SFR from its steady-state value. The transitory rise in the SFR can be met by substituting from 1-period external funding to deposit or long-term bond funding, or by reducing both 1-period funding and loans. In the model, long-term bond markets are estimated to be very liquid ($\kappa_m \approx 0$) and hence the cost of increasing bond funding is effectively the cost of shifting 5% of 1-period funding to bond funding. Given the model calibration, the shift from short-term wholesale funding to long-term wholesale funding, translates to an additional cost of about 120 basis points per annum. The higher cost, applied to 5% of funding, increases the loan spread to about 6 basis points at the 1-year horizon. Higher debt service costs put pressure on the household budget, and consequently, the household reduces demand for loans and reduces expenditures on consumption and investment. The fall in demand puts downward pressure on inflation leading to a monetary policy easing of about the same magnitude as the initial spread shock.

Can time-variation in the SFR improve trade-offs from the monetary policy perspective? We now assess the monetary policy implications of a variety of SFR rules, abstracting from the exogenous component studied above. We use, as proxy indicators of systemic risk, the same set of financial indicator variables considered in the previous section, namely, interest rate spreads and measures of credit and asset prices. To assess the effects of a direct SFR response to those

[24] For details on the macroprudential toolkit of the Reserve Bank of New Zealand, see http://www.rbnz.govt.nz/financial_stability/macro-prudential_policy/5266657.html.

proxy indicators of systemic risk, we include an additional term $\nu_x x_t$ in the SFR policy rule:

$$\tilde{\nu}_t^{sfr} = \rho_{sfr}\tilde{\nu}_{t-1}^{sfr} + \left(1 - \rho_{sfr}\right)\left(\nu_\tau \tilde{\tau}_t^m + \nu_x x_t\right), \tag{44}$$

where $x$ is a potential indicator of systemic risk. How would the monetary authority recommend that SFR policy be implemented, to support the monetary policy function?[25]

We continue to set the SFR response to the bond spread $\nu_\tau$ to zero, in order to remove the mild procyclicality estimated in the historical data. We present the optimised coefficients and associated changes in monetary policy losses, in Panel (b) of Table 6. A striking similarity with the results for the optimised augmented monetary policy rules in Panel (a), is that systematic SFR responses to the current account (*i.e.*, the negative of net loan growth), diminish monetary policy welfare losses. The optimal coefficient for this indicator variable is negative, implying that a tightening of the SFR when the current account deficit worsens reduces macroeconomic volatility. We also observe that losses are reduced when the SFR reacts to other measures of credit such as loans and net foreign debt, or asset prices. However the signs of the optimal coefficients, for example a loosening of the SFR for a rise in loans, are counter-intuitive.[26]

Overall, our results indicate that the presence of the time-varying SFR leaves loss-miminising monetary policy rule coefficients relatively unchanged. These results can again be explained by the weight on the time-varying ratio of long-term bonds to loans, in the internal cost of loans in Equation (42). Observe that the steady-state funding spread $\bar{\tau}^m$ determines the influence of the share of long-term liabilities which is in turn regulated by the SFR. This key parameter is given a very small value in the calibration – at the sample mean of 0.38%. Hence it is not surprising that the time-varying share of long-term bonds, which the cyclical component of the SFR directly influences, plays little role in influencing the bank's cost of funds and is consequently hardly influential in determining the dynamics of the economy. The result that optimised monetary policy rules remain very similar to the baseline case, suggests that monetary and macroprudential policy can be operated independently.

[25] To inform on what is desirable from a financial stability perspective, we would need to define a financial stability loss function, which is beyond the scope of the current paper. Angelini, Neri, and Panetta (2014) and Gelain and Ilbas (2014) examine issues of strategic coordination between monetary policy and capital requirements, using separate loss functions for the monetary and macroprudential authorities.

[26] Optimal SFR and monetary policy responses to movements in the current account, reduce macroeconomic volality even when we use loss functions from the literature presented in Equations (35) , (36) , and (37). However, the optimal coefficients underpinning the result in these experiments, are at times empirically unrealistic. These additional results are available on request.

# 5 Conclusion

This paper introduced a stable funding requirement, in the spirit of the Basel III NSFR, into a small open economy New Keynesian model. The central innovation that facilitated the modelling of this policy instrument is the introduction of a bank with a richly-specified liability side that includes short-term wholesale funding as well as stable funding in the form of deposits and long-term wholesale funding. The stable funding requirement regulates the proportion of the bank's liabilities held in long-term bonds and deposits, as opposed to short-term wholesale funding. The model was estimated for New Zealand where a similar policy instrument has been operational since 2010. Finally, we evaluated the implications of the macroprudential instrument for monetary policy trade-offs and assessed the effects on optimal policy rules derived from the central bank's loss function.

Taking into account the influence of all the estimated structural shocks, the presence of the stable funding requirement makes little difference to loss-minimising monetary policy rules, since it only alters the composition of bank funding. However, conditional on the bank funding spread shock which makes long-term financing expensive, the stable funding requirement worsens volatility-based losses. This finding is explained by the role of the stable funding requirement as an amplifier of the transmission of spread shocks; if a higher proportion of the bank's liabilities are held in long-term bonds when the spreads on these bonds rise, the effect on domestic lending rates is stronger and hence economic activity contracts further. We find that this additional volatility can be reduced if monetary policy 'leans against the wind' by responding directly to measures of credit – loan growth and the current account – so that the economy's exposure to the funding spread shock is limited. In a similar vein, monetary policy losses can also be reduced, if the prudential tool reacts to the current account. Even so, the optimal monetary policy responses to inflation and the output-gap do not change substantially. From the perspective of the monetary policy loss function, monetary and prudential policies can be operated independently.

Our results are conditional on several constraints imposed by our modelling choices. Since the stable funding requirement affects the cost of funding for the bank, its macroeconomic consequences may change when the funding spread endogenously reacts to other structural shocks. In our model, the funding spread is assumed to be exogenous, an assumption suited to a small open economy like New Zealand, but less reasonable for larger, more closed economies. We have allowed for longer maturities on the liability side of the bank's balance sheet, and that cost-structure is passed through to loans. In terms of cost-structure, the bank does not engage in maturity transformation. Hence, the prudential policy may have different effects when the bank engages in maturity transformation, *e.g.* as in Andreasen, Ferman, and Zabczyk (2013). As far as modelling the prudential instrument is concerned, we have used a conventional symmetric function to penalise deviations from the stable funding requirement. A more realistic approach would be to impose a floor on the share of stable funding and penalise any deviation that falls below the target floor. Incorporating this non-linearity would entail the use of more complex solution strategies, moving beyond the class of the linearised general equilibrium models used in this paper. We leave these extensions for future research.

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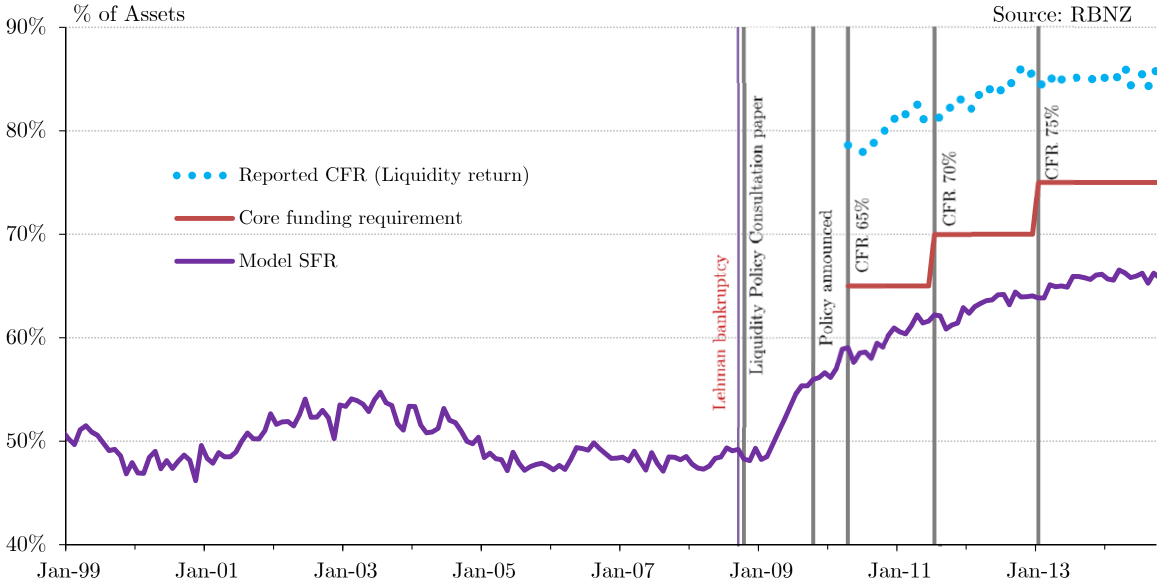
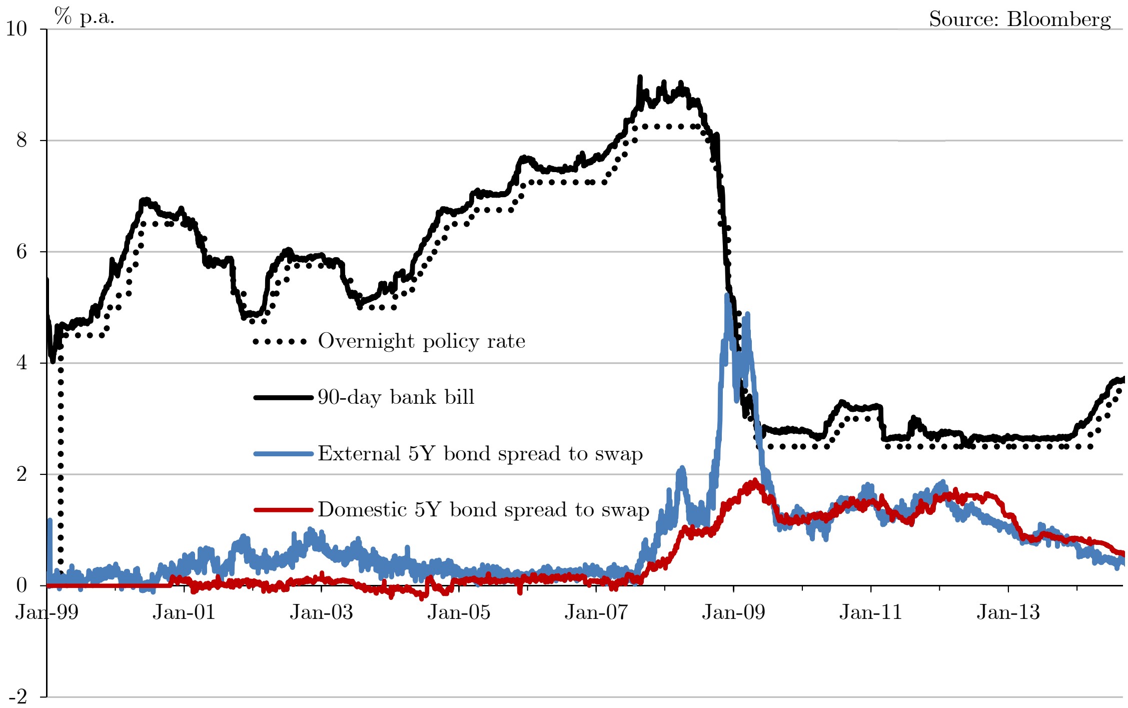
Figure 1: The Stable Funding Requirement and the Funding Spread in New Zealand

(a) The Stable Funding Ratio: Timeline



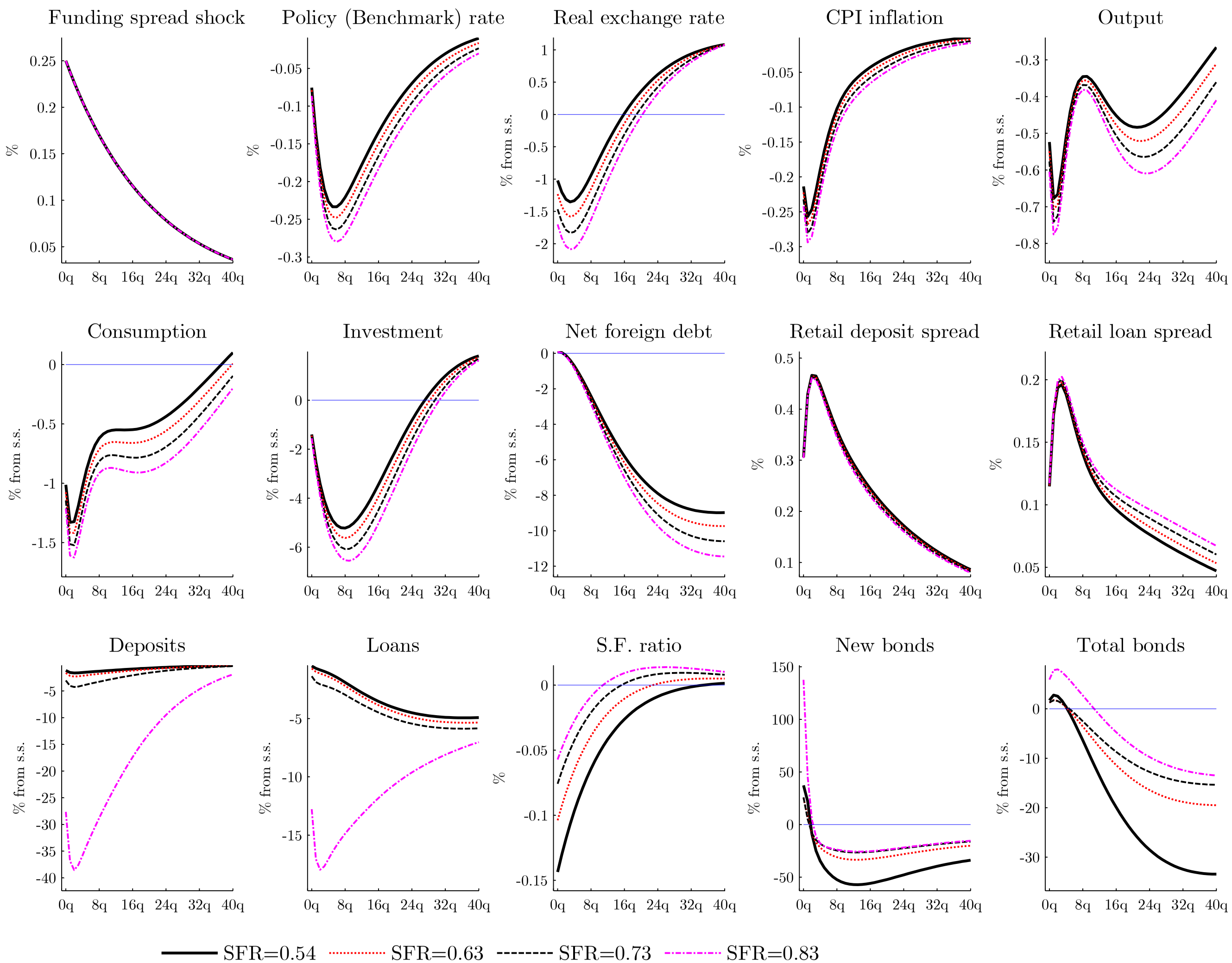

Note: The definitions of the model SFR and the New Zealand Core Funding Requirement (CFR) are slightly different. The CFR includes equity capital which is not in our model, and its denominator is less liquid assets. The model SFR is defined as deposits plus long-term wholesale funding divided by total funding ex-capital.

(b) Benchmark Interest Rates and Bond Spreads



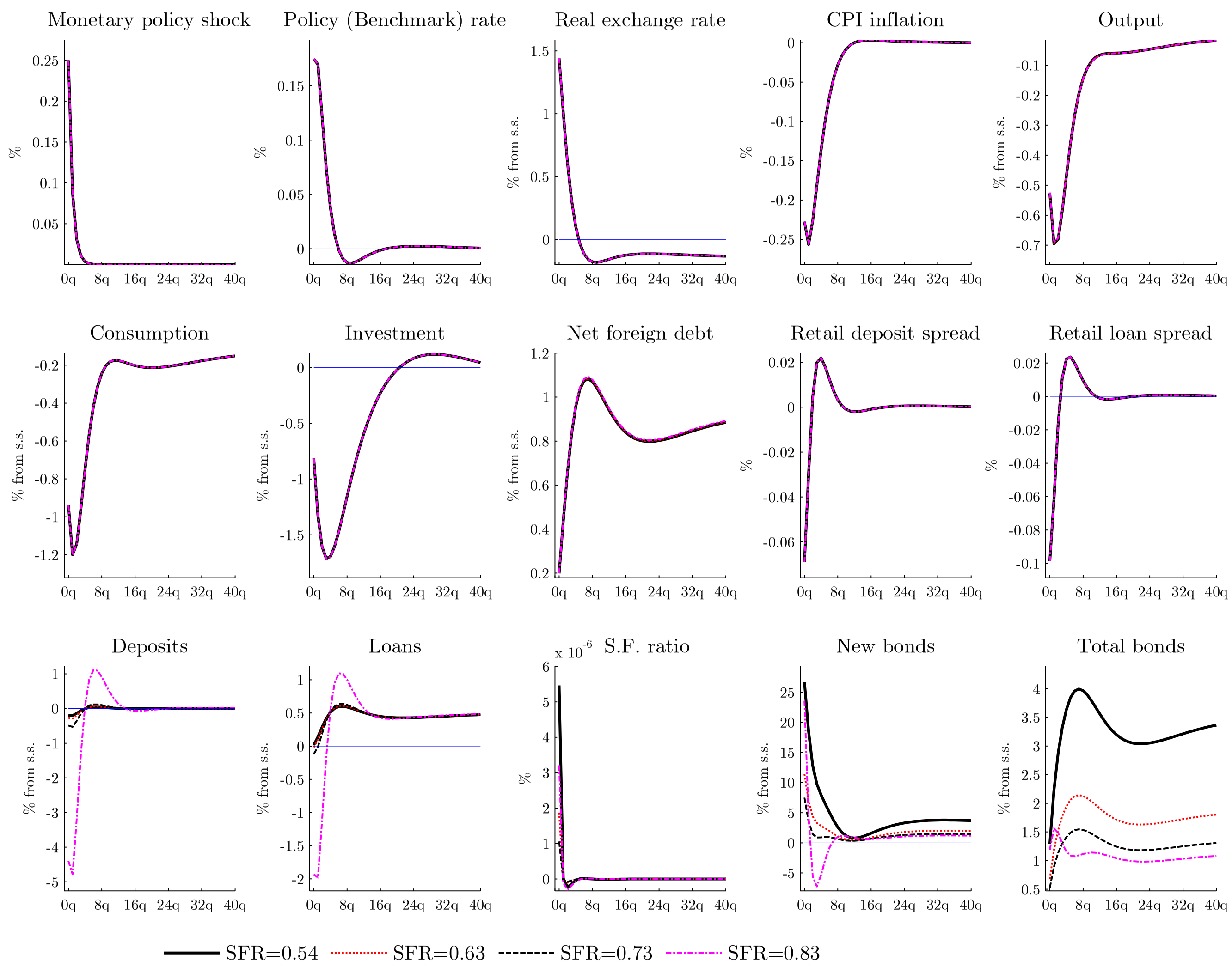

Note: External bond spread is USD AA 5Y finance bond yield less USD 5Y interest rate swap plus NZD cross currency basis swap. The interest rate swap is the expected cost of short-term funding over a longer horizon and includes a term premium. The basis swap is the cost of swapping USD funding to NZD.

Figure 2: Dynamics triggered by a funding spread shock when the steady-state SFR is varied



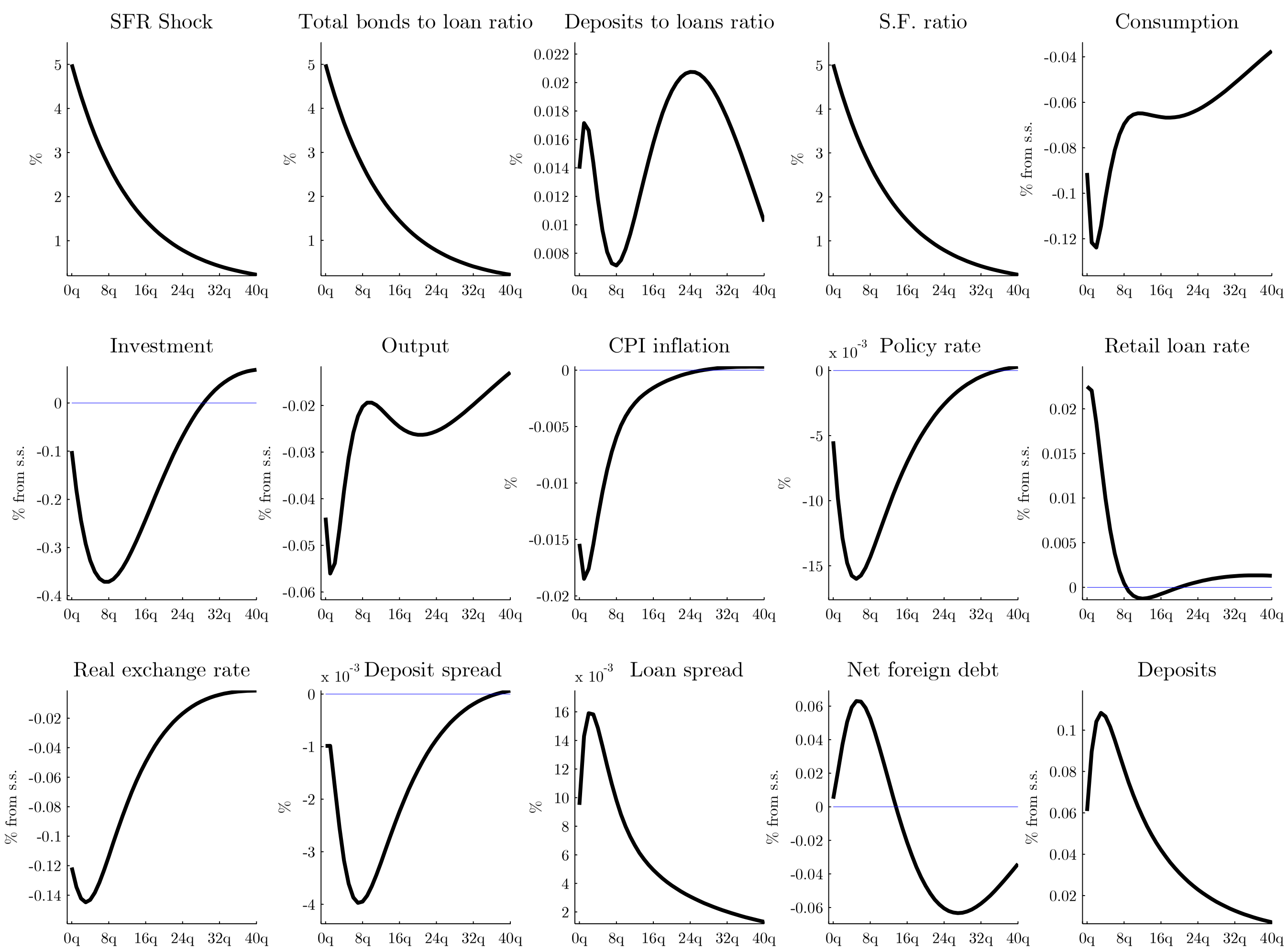

Note: The size of the shock is not set at the estimated value for expositional reasons. All other structural parameters are set at the posterior mode. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.

Figure 3: Dynamics triggered by a monetary policy shock when the steady-state SFR is varied



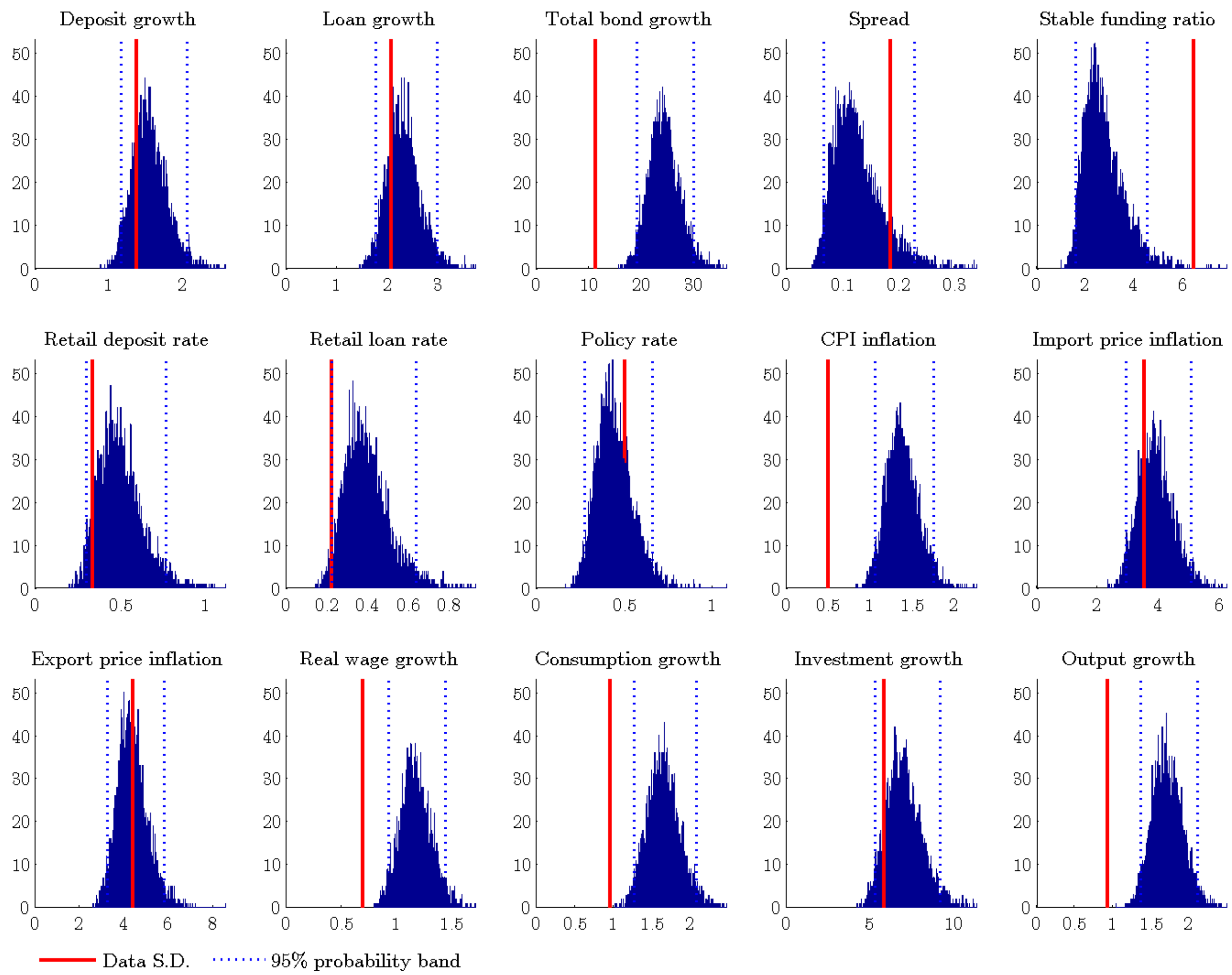

Note: The size of the shock is not set at the estimated value for expositional reasons. All other structural parameters are set at the posterior mode. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.

Figure 4: Dynamics triggered by a stable funding requirement shock



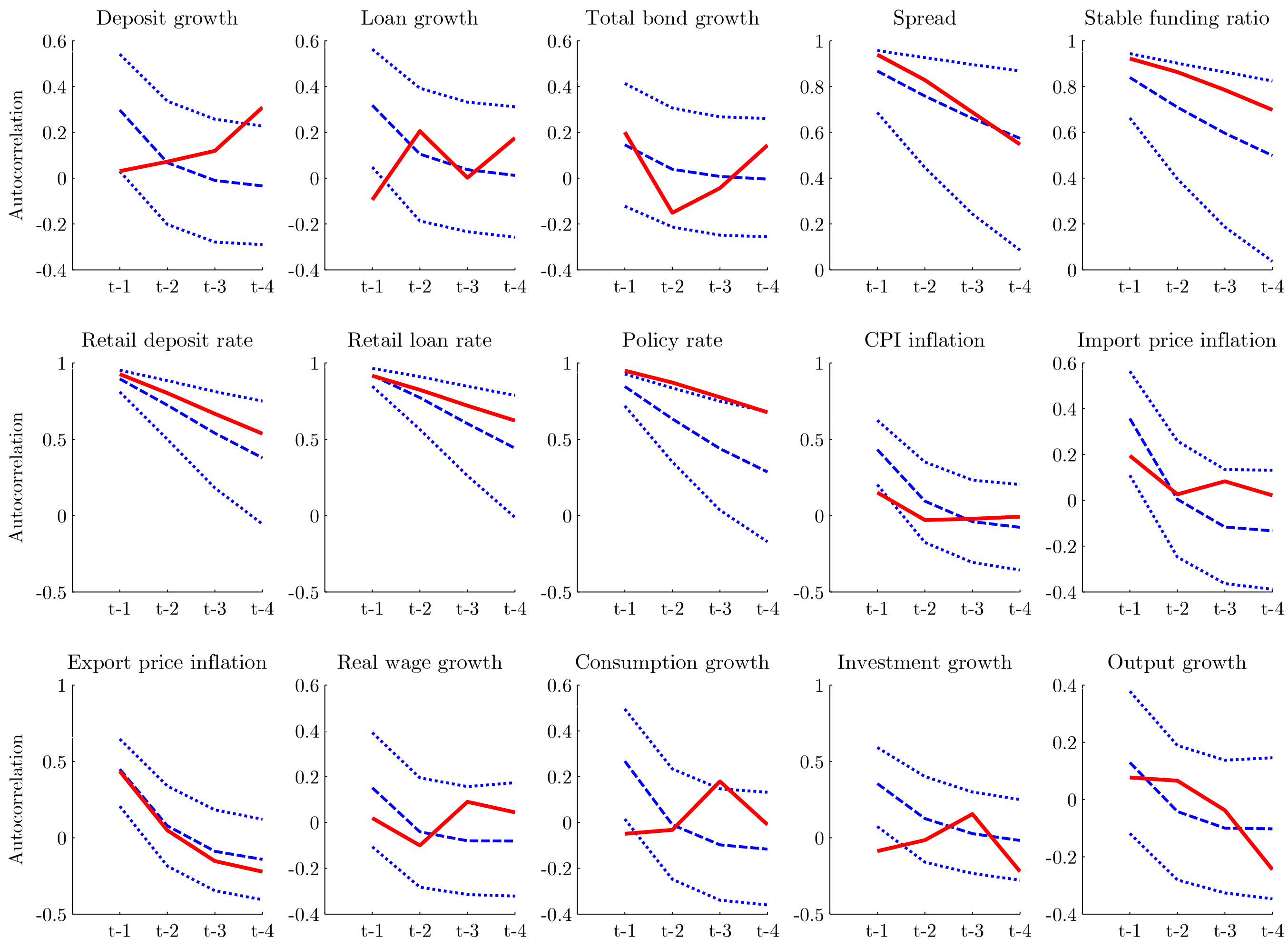

Note: The size of the shock is not set at the estimated value for expositional reasons. All other structural parameters are set at the posterior mode. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.

Figure 5: Posterior distributions of the volatilities of simulated model variables




Note: The size of the shock is not set at the estimated value for expositional reasons. All other structural parameters are set at the posterior mode. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.

Figure 6: Autocorrelations of simulated model variables




Note: The size of the shock is not set at the estimated value for expositional reasons. All other structural parameters are set at the posterior mode. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.

Table 1: Data

| Description | Mnemonic | Source | Transformation |
|---|---|---|---|
| HLFS: working age population | $pop$ | Statistics New Zealand | - |
| 90-day bank bill interest rate | $r_{90}$ | RBNZ | $(r_{90,t} - \bar{\mu}_1)/4$ |
| 6-month term deposit rate | $r_D$ | RBNZ | $(r_{D,t} - \bar{\mu}_2)/4$ |
| Effective mortgage rate | $r_L$ | RBNZ | $(r_{L,t} - \bar{\mu}_3)/4$ |
| CPI index | $CPI$ | Statistics New Zealand | $100\Delta\log(CPI_t) - \bar{\mu}_4$ |
| Import price | $PM$ | Statistics New Zealand (OTI) | $100\Delta\log(PM_t) - \bar{\mu}_5$ |
| Export price | $PX$ | Statistics New Zealand (OTI) | $100\Delta\log(PX_t) - \bar{\mu}_6$ |
| Average hourly wage, private sector | $W_{obs}$ | Statistics New Zealand (QES) | $100\Delta\log(W_{obs,t}/CPI_t) - \bar{\mu}_7$ |
| Deposits | $D_{obs}$ | RBNZ SSR data | $100\Delta\log(D_{obs,t}/pop_t/CPI_t) - \bar{\mu}_8$ |
| Wholesale funding $\geq$ 1 year maturity | $S^m_{obs}$ | RBNZ SSR data | $100\Delta\log(S^m_{obs,t}/pop_t/CPI_t) - \bar{\mu}_9$ |
| Total funding, ex capital | $L_{obs}$ | RBNZ SSR data | $100\Delta\log(L_{obs,t}/pop_t/CPI_t) - \bar{\mu}_{10}$ |
| 5-year external funding spread | $\tau_{obs}$ | Bloomberg | $\tau_{obs,t}/4 - \bar{\mu}_{11}$ |
| Stable funding ratio (calculated) | $sfr_{obs}$ | RBNZ SSR data | $(D_{obs,t} + S^m_{obs,t})/(L_{obs,t}) - \bar{\mu}_{12}$ |
| Real private consumption (s.a.) | $c_{obs}$ | Statistics New Zealand | $100\Delta\log(c_{obs,t}/pop_t) - \bar{\mu}_{13}$ |
| Real private gross fixed capital formation (s.a.) | $i_{obs}$ | Statistics New Zealand | $100\Delta\log(i_{obs,t}/pop_t) - \bar{\mu}_{14}$ |
| Real production GDP (s.a.) | $y_{obs}$ | Statistics New Zealand | $100\Delta\log(y_{obs,t}/pop_t) - \bar{\mu}_{15}$ |

Note: The spread is measured as the US dollar 5-year AA bond index - 5-year US dollar interest rate swap. + 5-year cross currency swap - 5-year New Zealand dollar interest rate swap. $\bar{\mu}_{()}$ indicates the respective sample means. The sample period we consider is 1998.Q4-2014.Q3. ‘s.a.’ indicates seasonally adjusted.

Table 2: Prior and posterior distributions of structural parameters

| Parameter Symbol | Description | Prior ($p_1$, $p_2$) | Mode | Mean | 2.5%ile | 97.5%ile |
|---|---|---|---|---|---|---|
| | | | | Posterior statistics | | |
| $\gamma_2$ | Curvature of SFR cost function | $\mathbb{N}$(5, 1.5) | 5.02 | 5.04 | 2.23 | 7.89 |
| $\omega_d$ | Elasticity of deposit demand | $\mathbb{N}$(50, 200) | 111.92 | 155.18 | 77.93 | 354.44 |
| $\kappa^L$ | Retail loan rate adjustment cost | $\mathbb{N}$(5, 1.5) | 9.49 | 9.54 | 7.47 | 11.79 |
| $\kappa^D$ | Retail deposit rate adjustment cost | $\mathbb{N}$(5, 1.5) | 7.27 | 7.34 | 5.04 | 9.67 |
| $\kappa^m$ | Bond adjustment cost | $\mathbb{N}$(0.1, 1) | 0 | 0 | 0 | 0 |
| $\nu_\tau$ | SFR reaction to spread | $\mathbb{N}$(0, 1) | 0.41 | 0.43 | -1.51 | 2.38 |
| $\gamma_c$ | External habit | $\mathbb{B}$(0.40, 0.05) | 0.47 | 0.48 | 0.38 | 0.57 |
| $\phi_i$ | Investment adjustment cost | $\mathbb{N}$(5, 1) | 4.81 | 4.96 | 3.52 | 6.55 |
| $\chi_{pd}$ | Domestic sales price adjustment cost | $\mathbb{N}$(205, 25) | 131.82 | 132.65 | 92.35 | 174.34 |
| $\iota_{pd}$ | Domestic sales price indexation | $\mathbb{B}$(0.50, 0.10) | 0.26 | 0.27 | 0.16 | 0.41 |
| $\chi_{pm}$ | Import sales price adjustment cost | $\mathbb{N}$(229, 25) | 222.87 | 222.07 | 172.87 | 270.09 |
| $\iota_{pm}$ | Import sales price indexation | $\mathbb{B}$(0.50, 0.10) | 0.29 | 0.30 | 0.17 | 0.44 |
| $\chi_{px}$ | Export sales price adjustment cost | $\mathbb{N}$(769, 25) | 765.21 | 764.87 | 715.18 | 815.82 |
| $\iota_{px}$ | Export sales price indexation | $\mathbb{B}$(0.50, 0.10) | 0.36 | 0.36 | 0.22 | 0.51 |
| $\chi_w$ | Nominal wage adjustment cost | $\mathbb{N}$(249, 25) | 303.22 | 303.43 | 259.77 | 349.01 |
| $\iota_w$ | Nominal wage indexation | $\mathbb{B}$(0.50, 0.10) | 0.40 | 0.41 | 0.25 | 0.59 |
| $r_R$ | Policy rate smoothing | $\mathbb{B}$(0.75, 0.05) | 0.85 | 0.85 | 0.81 | 0.88 |
| $r_\pi$ | Policy rate reaction to inflation | $\mathbb{G}$(2, 0.10) | 1.96 | 1.97 | 1.78 | 2.16 |
| $r_y$ | Policy rate reaction to output | $\mathbb{N}$(0.15, 0.10) | 0.04 | 0.05 | -0.04 | 0.15 |
| $\bar{\beta}$ | S.S. discount factor | 0.9879 | | | - | |
| $\bar{\beta}\beta_c$ | Elasticity of discount factor (rescaled) | 0.01 | | | - | |
| $\delta_k$ | Capital depreciation | 0.025 | | | - | |
| $\alpha$ | Capital share of production | 0.30 | | | - | |
| $m_c$ | Import-share of consumption | 0.20 | | | - | |
| $m_i$ | Import-share of investment | 0.68 | | | - | |
| $\eta_c$, $\eta_i$ | Price elasticities of import demand | 0.52 | | | - | |
| $\eta_x$ | Price elasticity of export demand | 0.81 | | | - | |
| $\bar{\mu}_{()}$ | S.S.price and wage markups | 1.1 | | | - | |
| $\omega_n$ | Inverse of Frisch elasticity of labour | 1.34 | | | - | |
| $\bar{y}_x/\bar{y}$ | S.S.exports to output ratio | 0.31 | | | - | |
| $\overline{es}/\bar{y}$ | S.S.exogenous spending to output ratio | 0.18 | | | - | |
| $\bar{\mu}^L$ | S.S.loan markup | 1.4 | | | - | |
| $\bar{\mu}^D$ | S.S.deposit markdown | 0.76 | | | - | |
| $\bar{d}/\bar{y}$ | S.S. deposits to output ratio | 3.2 | | | - | |
| $\bar{\tau}^m$ | S.S.spread | 0.0038 | | | - | |
| $\bar{d}^m$ | Average duration of bonds | 20 | | | - | |
| $\bar{\nu}^{sfr}$ | S.S.SFR | 0.54 | | | - | |
| $\overline{nfd}/\bar{y}$ | S.S.net foreign debt to output ratio | 2.8 | | | - | |

Note: $\mathbb{G} \equiv$ Gamma distribution, $\mathbb{B} \equiv$ Beta distribution, $\mathbb{IG} \equiv$ Inverse gamma distribution and $\mathbb{N} \equiv$ Normal distribution. $p_1 \equiv$ mean and $p_2 \equiv$ standard deviation for all distributions. S.S. represents steady-state. Other steady-state parameters are derived from the restrictions of the model. Posterior moments are computed from 5000 random draws from the simulated posterior distribution.

Table 3: Prior and posterior distributions of shock parameters

| Parameter Symbol | Description | Prior ($p_1$,$p_2$) | Mode | Posterior statistics Mean | 2.5%ile | 97.5%ile |
|---|---|---|---|---|---|---|
| $\rho_L$ | AR(1) Loan markup shock | $\mathbb{B}$(0.50, 0.10) | 0.83 | 0.82 | 0.70 | 0.91 |
| $\rho_D$ | AR(1) Deposit markdown shock | $\mathbb{B}$(0.50, 0.10) | 0.76 | 0.75 | 0.65 | 0.84 |
| $\rho_\tau$ | AR(1) Spread shock | $\mathbb{B}$(0.50, 0.10) | 0.95 | 0.95 | 0.95 | 0.95 |
| $\rho_{sfr}$ | AR(1) SFR Shock | $\mathbb{B}$(0.50, 0.10) | 0.93 | 0.92 | 0.88 | 0.95 |
| $\rho_{mp}$ | AR(1) Monetary policy shock | $\mathbb{B}$(0.50, 0.10) | 0.35 | 0.36 | 0.24 | 0.47 |
| $\rho_\beta$ | AR(1) Consumption shock | $\mathbb{B}$(0.50, 0.10) | 0.59 | 0.56 | 0.39 | 0.71 |
| $\rho_i$ | AR(1) Investment shock | $\mathbb{B}$(0.50, 0.10) | 0.33 | 0.33 | 0.20 | 0.48 |
| $\rho_{es}$ | AR(1) Exogenous spending shock | $\mathbb{B}$(0.50, 0.10) | 0.77 | 0.76 | 0.65 | 0.85 |
| $\rho_{tfp}$ | AR(1) Technology shock | $\mathbb{B}$(0.50, 0.10) | 0.32 | 0.31 | 0.19 | 0.44 |
| $\rho_{pm}$ | AR(1) Import price markup shock | $\mathbb{B}$(0.50, 0.10) | 0.26 | 0.26 | 0.15 | 0.38 |
| $\rho_{px}$ | AR(1) Export price markup shock | $\mathbb{B}$(0.50, 0.10) | 0.30 | 0.31 | 0.19 | 0.43 |
| $\rho_w$ | AR(1) Wage markup shock | $\mathbb{B}$(0.50, 0.10) | 0.41 | 0.40 | 0.27 | 0.54 |
| $\rho^{me}_{\Delta\ell}$ | AR(1) Measurement error for loans | $\mathbb{B}$(0.50, 0.10) | 0.27 | 0.29 | 0.16 | 0.44 |
| $\rho^{me}_{\Delta d}$ | AR(1) Measurement error for deposits | $\mathbb{B}$(0.50, 0.10) | 0.31 | 0.33 | 0.19 | 0.48 |
| $\rho^{me}_{\Delta b}$ | AR(1) Measurement error for bonds | $\mathbb{B}$(0.50, 0.10) | 0.31 | 0.32 | 0.19 | 0.48 |
| $\sigma_L$ | SD Loan markup shock | $\mathbb{IG}$(0.10, 2) | 0.03 | 0.03 | 0.03 | 0.04 |
| $\sigma_D$ | SD Deposit markup shock | $\mathbb{IG}$(0.10, 2) | 0.11 | 0.12 | 0.09 | 0.16 |
| $\sigma_\tau$ | SD Spread shock | $\mathbb{IG}$(0.10, 2) | 0.05 | 0.05 | 0.05 | 0.06 |
| $\sigma_{sfr}$ | SD SFR shock | $\mathbb{IG}$(0.10, 2) | 1.26 | 1.31 | 1.09 | 1.59 |
| $\sigma_{mp}$ | SD Monetary policy shock | $\mathbb{IG}$(0.10, 2) | 0.12 | 0.12 | 0.10 | 0.15 |
| $\sigma_\beta$ | SD Consumption shock | $\mathbb{IG}$(0.10, 2) | 0.34 | 0.37 | 0.25 | 0.52 |
| $\sigma_i$ | SD Investment shock | $\mathbb{IG}$(0.10, 2) | 2.37 | 2.42 | 1.94 | 2.97 |
| $\sigma_{es}$ | SD Exogenous spending shock | $\mathbb{IG}$(0.10, 2) | 1.08 | 1.11 | 0.94 | 1.33 |
| $\sigma_{tfp}$ | SD Technology shock | $\mathbb{IG}$(0.10, 2) | 0.49 | 0.50 | 0.41 | 0.61 |
| $\sigma_{pm}$ | SD Import price markup shock | $\mathbb{IG}$(0.10, 2) | 2.58 | 2.62 | 2.15 | 3.18 |
| $\sigma_{px}$ | SD Export price markup shock | $\mathbb{IG}$(0.10, 2) | 2.47 | 2.51 | 2.03 | 3.08 |
| $\sigma_w$ | SD Wage markup shock | $\mathbb{IG}$(0.10, 2) | 0.72 | 0.74 | 0.58 | 0.94 |
| $\sigma^{me}_{\Delta\ell}$ | SD Measurement error for loans | $\mathbb{IG}$(0.10, 2) | 1.93 | 1.98 | 1.66 | 2.40 |
| $\sigma^{me}_{\Delta d}$ | SD Measurement error for deposits | $\mathbb{IG}$(0.10, 2) | 1.29 | 1.34 | 1.12 | 1.63 |
| $\sigma^{me}_{\Delta b}$ | SD Measurement error for bonds | $\mathbb{IG}$(0.10, 2) | 14.47 | 14.83 | 12.46 | 17.70 |

Note: $\mathbb{G}$ ≡ Gamma distribution, $\mathbb{B}$ ≡ Beta distribution, $\mathbb{IG}$ ≡ Inverse gamma distribution and $\mathbb{N}$ ≡ Normal distribution. $p_1$ ≡ mean and $p_2$ ≡ standard deviation for all distributions.

Table 4: Optimal monetary policy rules for various loss functions

| | Optimal coefficients[a] | | | Distance[b] | Loss function weights[c] | | |
|---|---|---|---|---|---|---|---|
| | $r_R^{opt}$ | $r_\pi^{opt}$ | $r_y^{opt}$ | | $\theta_{(\pi)}$ | $\theta_{(x_1)}$ | $\theta_{(x_2)}$ |
| 1-variable loss function | | | | | | | |
| $\tilde{\pi}_t$ | 0.488 | 88.24 | -2.56 | 87.44 | 1 | - | - |
| 3-variable loss functions | | | | | | | |
| $\tilde{\pi}_t$, $\hat{y}_t$, $\tilde{r}_t$ | 0.935 | 1.977 | 0.388 | 0.36 | 1 | 0.36 | 3.48 |
| $\tilde{\pi}_t$, $\hat{y}_t$, $\Delta\tilde{r}_t$ | 0.913 | 1.985 | 0.401 | 0.37 | 1 | 0.24 | 4.34 |
| $\tilde{\pi}_t$, $\hat{y}_t$, $\widehat{rer}_t$ | 0.799 | 1.969 | 0.242 | 0.21 | 1 | - | 0.14 |
| $\tilde{\pi}_t$, $\hat{y}_t$, $\Delta\widehat{rer}_t$ | 0.803 | 1.964 | 0.022 | 0.05 | 1 | - | 0.33 |
| $\tilde{\pi}_t$, $\Delta\hat{y}_t$, $\tilde{r}_t$ | 0.398 | 11.030 | -0.570 | 9.10 | 1 | 0.36 | - |
| $\tilde{\pi}_t$, $\Delta\hat{y}_t$, $\Delta\tilde{r}_t$ | 0.400 | 12.538 | -0.654 | 10.61 | 1 | 1.35 | - |
| $\tilde{\pi}_t$, $\Delta\hat{y}_t$, $\widehat{rer}_t$ | 0.799 | 1.969 | 0.242 | 0.21 | 1 | 0.18 | 0.14 |
| $\tilde{\pi}_t$, $\Delta\hat{y}_t$, $\Delta\widehat{rer}_t$ | 0.803 | 1.964 | 0.022 | 0.05 | 1 | 0.09 | 0.33 |
| $\tilde{\pi}_t$, $\tilde{r}_t$, $\widehat{rer}_t$ | 0.896 | 1.963 | 0.197 | 0.16 | 1 | 3.19 | 0.16 |
| $\tilde{\pi}_t$, $\tilde{r}_t$, $\Delta\widehat{rer}_t$ | 0.857 | 1.959 | 0.035 | 0.009 | 1 | 1.74 | 0.55 |
| $\tilde{\pi}_t$, $\Delta\tilde{r}_t$, $\widehat{rer}_t$ | 0.839 | 1.967 | 0.222 | 0.18 | 1 | 1.24 | 0.12 |
| $\tilde{\pi}_t$, $\Delta\tilde{r}_t$, $\Delta\widehat{rer}_t$ | 0.866 | 1.958 | 0.041 | 0.015 | 1 | 6.82 | 0.44 |

a. The monetary policy reaction function shown for each class of loss function, is the closest to the estimated rule among all rules computed across the set of loss function weights.
b. Distance is defined as the square root of the sum of the squared differences between the estimated Taylor rule parameters ($r_R = 0.851,\ r_\pi = 1.960,\ r_y = 0.042$) and the coefficients from the optimal policy rule for that loss function specification.
c. The range of loss function weights that we use for the grid-search is: $\theta_y \in [0,\ 0.8]$, $\theta_{\Delta y} \in [0,\ 1.7]$, $\theta_r \in [0,\ 5.8]$, $\theta_{\Delta r} \in [0,\ 12.3]$, $\theta_{rer} \in [0,\ 0.4]$ and $\theta_{\Delta rer} \in [0,\ 2.2]$.

Table 5: Monetary policy welfare losses at higher steady-state SFR levels

| | Specifications | Fixed | | Panel (a) Changes in losses from baseline in all loss function specifications: Functional form | | | | Panel (b) Optimised policy rules for $L_4$: Optimised | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $\bar{\upsilon}^{sfr}$ | $\upsilon_\tau$ | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $r_R^{opt}$ | $r_\pi^{opt}$ | $r_y^{opt}$ |
| All shocks | Baseline | 0.54 | 0.41 | - | - | - | - | 0.857 | 1.96 | 0.035 |
| | Acyclical SFR | 0.54 | 0 | -0.01% | -0.04% | -0.02% | -0.02% | 0.857 | 1.96 | 0.035 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.54 | - | -0.02% | 0.02% | -0.04% | -0.05% | 0.857 | 1.96 | 0.035 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.63 | - | 0.3% | 1.7% | 2.1% | 1.00% | 0.858 | 1.96 | 0.035 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.73 | - | 0.9% | 3.7% | 4.5% | 2.30% | 0.855 | 1.9 | 0.034 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.83 | - | 1.6% | 5.8% | 6.7% | 3.70% | 0.86 | 1.96 | 0.035 |
| No spread shocks | Baseline | 0.54 | 0.41 | - | - | - | - | 0.838 | 1.8 | 0.028 |
| | Acyclical SFR | 0.54 | 0 | 0.00% | -0.01% | -0.05% | 0.00% | 0.838 | 1.8 | 0.028 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.54 | - | 0.02% | -0.01% | -0.03% | -0.03% | 0.838 | 1.8 | 0.028 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.63 | - | 0.0% | 0.1% | -0.1% | -0.03% | 0.838 | 1.8 | 0.028 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.73 | - | 0.0% | 0.1% | 0.0% | -0.03% | 0.838 | 1.8 | 0.028 |
| | $\tilde{\nu}_t^{sfr} = 0$ | 0.83 | - | 0.0% | 0.1% | 0.0% | -0.03% | 0.838 | 1.8 | 0.028 |

Note: Loss function specifications $L_1$ and $L_2$ represent the functional forms $\tilde{\pi}_t^2 + \tilde{r}_t^2$ and $\tilde{\pi}_t^2 + 0.5\hat{y}_t^2 + \tilde{r}_t^2$ drawn from Justiniano and Preston (2010). $L_3$ refers to the function $\tilde{\pi}_t^2 + 0.41\hat{y}_t^2 + 0.61\tilde{r}_t^2 + 0.005\widehat{rer}_t^2$ drawn from Kam, Lees, and Liu (2009) and $L_4$ refers to the model-specific loss function $\tilde{\pi}_t^2 + 1.74\tilde{r}_t^2 + 0.55\Delta\widehat{rer}_t^2$. 'Acyclical SFR' refers to the experiment where we eliminate the systematic reaction of the SFR to the funding spread (set $\upsilon_\tau = 0$). In the next set of experiments, we abstract from any time-variation in the SFR (set $\tilde{\nu}_t^{sfr} = 0$), and increase the steady-state SFR. Invariant parameters are set at the posterior mode. The benchmark for each loss function, is the loss computed at the baseline parameter values, and we report the percentage change in loss when the parameters are changed.

Table 6: Optimal policy responses to additional indicator variables with the model-specific loss function

| | Panel (a) Monetary policy | | | | | Panel (b) SFR policy | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Optimised coefficients | | | | | Optimised coefficients | | | | |
| *Indicator variable (x)* | $r_R^{opt}$ | $r_\pi^{opt}$ | $r_y^{opt}$ | $r_{(x)}^{opt}$ | $\Delta$ change in loss | $r_R^{opt}$ | $r_\pi^{opt}$ | $r_y^{opt}$ | $\nu_{(x)}^{opt}$ | $\Delta$ change in loss |
| Baseline (no indicator) [a] | 0.86 | 1.96 | 0.04 | - | - | 0.86 | 1.96 | 0.04 | - | - |
| Bond spread | 0.86 | 1.96 | 0.04 | -0.0003 | 0 | 0.86 | 1.96 | 0.04 | 0 | 0 |
| Deposit spread | 0.86 | 1.95 | 0.04 | 0.037 | 0 | 0.86 | 1.96 | 0.04 | 0 | 0 |
| Loans/Output | 0.86 | 1.96 | 0.04 | 0 | 0 | 0.85 | 1.84 | 0.03 | -0.06 | -1.3% |
| Net foreign debt/Output | 0.86 | 1.96 | 0.04 | 0 | 0 | 0.85 | 1.84 | 0.03 | -0.06 | -1.4% |
| Asset price | 0.86 | 1.96 | 0.04 | 0.003 | 0 | 0.85 | 1.91 | 0.03 | -2.66 | -1.7% |
| Loan growth | 0.82 | 1.95 | -0.01 | 0.383 | -2.9% | 0.86 | 1.96 | 0.04 | 0 | 0 |
| Current account | 0.81 | 1.48 | 0.00 | -0.060 | -2.1% | 0.83 | 1.69 | 0.03 | -7.43 | -1.1% |

*a*. Estimated model, except that the systematic reaction of the SFR to the funding spread set to zero. Tobin's Q represents the asset price. The benchmark is the loss computed at the baseline parameter values, and we report the percentage change in loss with the addition of each indicator variable.

Table 7: Unconditional variance decomposition of selected variables

| | Financial shocks | | | | Real economy shocks | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Variables* | | | | | Demand | | | | Supply | | | |
| | $\mu^L$ | $\mu^D$ | $\tau^m$ | $\nu^{sfr}$ | $\varepsilon_{mp}$ | $\varepsilon_\beta$ | $\varepsilon_i$ | $\varepsilon_{es}$ | $\varepsilon_{tfp}$ | $\mu_{pm}$ | $\mu_{px}$ | $\mu_n$ |
| Retail deposit rate | 3.82 | 14.43 | 14.13 | 0.09 | 4.60 | 3.04 | 9.14 | 2.69 | 13.67 | 12.66 | 13.41 | 8.34 |
| Retail loan rate | 2.31 | 0.07 | 2.87 | 0.01 | 5.07 | 4.25 | 15.77 | 3.92 | 16.04 | 17.62 | 20.26 | 11.81 |
| Deposits | 19.88 | 38.16 | 37.55 | 0.20 | 0.68 | 0.08 | 0.07 | 0.10 | 1.53 | 1.15 | 0.30 | 0.32 |
| Loans | 1.22 | 1.85 | 31.91 | 0.00 | 1.86 | 0.32 | 5.21 | 0.04 | 2.46 | 50.31 | 4.73 | 0.09 |
| Total bonds | 1.02 | 1.58 | 28.85 | 7.34 | 1.75 | 0.30 | 4.92 | 0.04 | 2.25 | 47.42 | 4.43 | 0.08 |
| SF ratio | 0.00 | 0.00 | 0.25 | 99.75 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| SF requirement | 0.00 | 0.00 | 0.22 | 99.78 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 90-day interest rate | 3.54 | 0.03 | 11.74 | 0.07 | 8.41 | 3.42 | 7.96 | 2.90 | 21.76 | 17.46 | 13.47 | 9.23 |
| CPI inflation | 0.34 | 0.00 | 0.74 | 0.00 | 2.90 | 0.69 | 1.13 | 0.50 | 49.98 | 39.09 | 1.76 | 2.85 |
| Import price inflation | 0.02 | 0.01 | 0.12 | 0.00 | 0.25 | 0.02 | 0.16 | 0.01 | 0.83 | 98.41 | 0.09 | 0.08 |
| Export price inflation | 0.04 | 0.01 | 0.08 | 0.00 | 0.02 | 0.01 | 0.07 | 0.02 | 0.09 | 0.14 | 99.49 | 0.04 |
| Real wage | 2.38 | 1.30 | 18.20 | 0.03 | 2.75 | 0.84 | 14.89 | 0.13 | 2.60 | 40.18 | 4.74 | 11.97 |
| Output | 0.96 | 0.04 | 3.20 | 0.01 | 3.44 | 5.51 | 29.07 | 13.10 | 3.12 | 11.64 | 26.00 | 3.89 |
| Consumption | 2.83 | 1.32 | 18.28 | 0.03 | 4.81 | 8.43 | 14.15 | 1.54 | 3.10 | 27.70 | 15.56 | 2.25 |
| Investment | 1.26 | 0.13 | 5.68 | 0.03 | 1.06 | 0.16 | 48.76 | 0.13 | 0.39 | 40.88 | 1.24 | 0.30 |

Note: $\mu^L \equiv$ retail loan markup shock, $\mu^D \equiv$ retail deposit markdown shock, $\tau^m \equiv$ bank funding spread shock, $\upsilon^{sfr} \equiv$ stable funding requirement shock, $\varepsilon_{mp} \equiv$ monetary policy shock, $\varepsilon_\beta \equiv$ consumption discount factor shock, $\varepsilon_i \equiv$ investment-specific shock, $\varepsilon_{es} \equiv$ exogenous spending shock, $\varepsilon_{tfp} \equiv$ technology shock, $\mu_{pm} \equiv$ import price markup shock, $\mu_{px} \equiv$ export price markup shock and $\mu_n \equiv$ wage markup shock. The variance decomposition reported above is the mean of variance decompositions computed from 5000 random draws from the posterior distribution. The 3 additional measurement errors used in the estimation play no role in the model dynamics and hence are not presented here.

# A Other Equilibrium Conditions

Here we list the optimality conditions for the non-banking segment of the model which were omitted from the main text. For brevity, we use gross interest rates and inflation notation: $R^L = 1 + r^L$, $\Pi_c = 1 + \pi_c$, $\Pi_m = 1 + \pi_m$, $\Pi_x = 1 + \pi_x$, and $\Pi^{nw} = 1 + \pi^{nw}$.

1. Consumption and investment Armington aggregators:

$$z_t = \left[ (1 - m_z)^{\frac{1}{\eta}} z_{d,t}^{\frac{\eta-1}{\eta}} + m_z^{\frac{1}{\eta}} z_{m,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}, \; z \in \{c, i\}, \tag{45}$$

where $\eta > 0$ and $m_z \in [0, 1]$. The subscripts $d$ and $m$ indicate domestic and import sales respectively. The nominal price deflators for consumption and investment are given by:

$$P_{z,t} = \left[ (1 - m_z) P_{d,t}^{1-\eta} + m_z P_{m,t}^{1-\eta} \right]^{\frac{1}{1-\eta}}, \; z \in \{c, i\}. \tag{46}$$

The sales for domestic and imported components of consumption and investment ($c_d, \; i_d, \; c_m, \; i_m$) and exports ($y_x^*$) are given by:

$$z_{d,t} = (1 - m_z) \left( \frac{P_{d,t}}{P_{z,t}} \right)^{-\eta} z_t, \; z_{m,t} = m_z \left( \frac{P_{m,t}}{P_{z,t}} \right)^{-\eta} z_t, \; z \in \{c, i\} \tag{47}$$

$$\text{and } y_{x,t}^* = \left( \frac{P_{x,t}}{P_t^*} \right)^{-\eta_x} y_t^*, \tag{48}$$

where $P_d^*$ and $y^*$ represent the aggregate price level and output in the foreign economy.

2. Euler equation for consumption $(c)$:

$$(c_t - \gamma_c c_{t-1})^{-1} = \mathbb{E}_t (c_{t+1} - \gamma_c c_t)^{-1} \beta_t \frac{\varepsilon_{\beta,t+1}}{\varepsilon_{\beta,t}} \frac{R_t^L}{\Pi_{c,t+1}}, \tag{49}$$

where $\varepsilon_{\beta,t} (c_t - \gamma_c c_{t-1})^{-1} = \lambda_t$ is the marginal utility of consumption (or wealth) and $\varepsilon_\beta$ is a shock stimulating intertemporal substitution.

3. Euler equation for capital stock $(k)$ which determines the flow of Tobin's q $(tq)$:

$$tq_t = \mathbb{E}_t \beta_t \frac{\lambda_{t+1}}{\lambda_t} \left[ r_{c,t+1}^k + tq_{t+1} (1 - \delta_k) \right], \tag{50}$$

where $\delta_k \in [0, \; 1]$ is the depreciation of the capital stock. $i_t \varepsilon_{i,t} \left[ 1 - \phi \left( \frac{i_t}{i_{t-1}} \right) \right] + (1 - \delta_k) k_{t-1} = k_t$ determines capital accumulation and $\varepsilon_i$ is an investment shock.

4. Euler equation for investment $(i)$:

$$\varepsilon_{i,t} tq_t \left[ 1 - \phi \left( \frac{i_t}{i_{t-1}} \right) - \frac{i_t}{i_{t-1}} \phi' \left( \frac{i_t}{i_{t-1}} \right) \right] + \mathbb{E}_t \beta_t \frac{\lambda_{t+1}}{\lambda_t} tq_{t+1} \varepsilon_{i,t+1} \frac{i_{t+1}^2}{i_t^2} \phi' \left( \frac{i_{t+1}}{i_t} \right) = \frac{P_{i,t}}{P_{c,t}}. \tag{51}$$

5. Nominal wage inflation $(\Pi^{nw})$ :

$$\mathbb{E}_t\beta_t\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\Pi_{c,t+1}}\frac{n_{t+1}}{n_t}\frac{\left(\Pi^{nw}_{t+1}\right)^2}{\Pi^{\iota_w}_{c,t}\bar{\Pi}^{1-\iota_w}_c}\chi_w\left(\frac{\Pi^{nw}_{t+1}}{\Pi^{\iota_w}_{c,t}\bar{\Pi}^{1-\iota_w}_c}-1\right) \tag{52}$$

$$= \frac{\Pi^{nw}_t}{\Pi^{\iota_w}_{c,t-1}\bar{\Pi}^{1-\iota_w}_c}\chi_w\left(\frac{\Pi^{nw}_t}{\Pi^{\iota_w}_{c,t-1}\bar{\Pi}^{1-\iota_w}_c}-1\right)+\vartheta_{n,t}\left[\begin{array}{c}1-\frac{\chi_w}{2}\left(\frac{\Pi^{nw}_t}{\Pi^{\iota_w}_{c,t-1}\bar{\Pi}^{1-\iota_w}_c}-1\right)^2\\ -n_t^{\omega_n}\frac{(c_t-\gamma_c c_{t-1})}{w_{c,t}}\end{array}\right]-1,$$

where $\Pi^{nw}_t=\frac{w_{c,t}}{w_{c,t-1}}\Pi_{c,t}$.

6. Production function:

$$y_t=\varepsilon_{tfp,t}k^{\alpha}_{t-1}n^{1-\alpha}_t,\ \ \alpha\in[0,\ 1], \tag{53}$$

where $\varepsilon_{tfp}$ is a neutral technology shock.

7. Substitution between factors of production obtained by combining labour and capital demand:

$$\frac{r^k_{d,t}k_{t-1}}{\alpha}=\frac{w_{d,t}n_t}{1-\alpha}, \tag{54}$$

where the subscript $d$ indicates that the factor prices have been deflated by the domestic sales price for goods $P_d$.

8. Real marginal cost:

$$rmc_{d,t}=\frac{1}{\varepsilon_{tfp,t}\alpha^{\alpha}(1-\alpha)^{1-\alpha}}\left(r^k_{d,t}\right)^{\alpha}w^{1-\alpha}_{d,t}. \tag{55}$$

9. Domestic sales price inflation $(\Pi_d)$:

$$\mathbb{E}_t\beta_t\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\Pi_{c,t+1}}\frac{y_{t+1}}{y_t}\frac{\Pi^2_{d,t+1}}{\Pi^{\iota_{pd}}_{d,t}\bar{\Pi}^{1-\iota_{pd}}_d}\chi_{pd}\left(\frac{\Pi_{d,t+1}}{\Pi^{\iota_{pd}}_{d,t}\bar{\Pi}^{1-\iota_{pd}}_d}-1\right) \tag{56}$$

$$= \frac{\Pi_{d,t}}{\Pi^{\iota_{pd}}_{d,t-1}\bar{\Pi}^{1-\iota_{pd}}_d}\chi_{pd}\left(\frac{\Pi_{d,t}}{\Pi^{\iota_{pd}}_{d,t-1}\bar{\Pi}^{1-\iota_{pd}}_d}-1\right)+\vartheta_{d,t}\left[\begin{array}{c}1-\frac{\chi_{pd}}{2}\left(\frac{\Pi_{d,t}}{\Pi^{\iota_{pd}}_{d,t-1}\bar{\Pi}^{1-\iota_{pd}}_d}-1\right)^2\\ -rmc_{d,t}\end{array}\right]-1.$$

$\chi_{pd}>0$ measures the associated price adjustment cost, $\iota_{pd}\in[0,1]$ measures the degree of price indexation and $\vartheta_d>1$ is the demand elasticity for domestic sales.

10. Export sales price inflation $(\Pi_x)$ :

$$\mathbb{E}_t\beta_t\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\Pi_{c,t+1}}\frac{y_{x,t+1}}{y_{x,t}}\frac{ner_t}{ner_{t+1}}\frac{\Pi^2_{x,t+1}}{\Pi^{\iota_{px}}_{x,t}\bar{\Pi}^{1-\iota_{px}}_x}\chi_{px}\left(\frac{\Pi_{x,t+1}}{\Pi^{\iota_{px}}_{x,t}\bar{\Pi}^{1-\iota_{px}}_x}-1\right) \tag{57}$$

$$= \frac{\Pi_{x,t}}{\Pi^{\iota_{px}}_{x,t-1}\bar{\Pi}^{1-\iota_{px}}_x}\chi_{px}\left(\frac{\Pi_{x,t}}{\Pi^{\iota_{px}}_{x,t-1}\bar{\Pi}^{1-\iota_{px}}_x}-1\right)+\vartheta_{x,t}\left[\begin{array}{c}1-\frac{\chi_{px}}{2}\left(\frac{\Pi_{x,t}}{\Pi^{\iota_{px}}_{x,t-1}\bar{\Pi}^{1-\iota_{px}}_x}-1\right)^2\\ -\frac{ner_tP_{d,t}}{P_{x,t}}\end{array}\right]-1.$$

$P_x$ is the foreign-currency price set by the exporter for the domestic good. $\chi_{px}>0$ moderates the price adjustment cost, $\iota_{px}\in[0,1]$ measures the degree of price indexation and $\vartheta_x>1$ is the demand elasticity for export sales.

11. Import sales price inflation $(\pi_m)$ :

$$\mathbb{E}_t\beta_t \frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\Pi_{c,t+1}}\frac{y_{m,t+1}}{y_{m,t}}\frac{\Pi^2_{m,t+1}\chi_{pm}}{\Pi^{\iota_{pm}}_{m,t}\bar{\Pi}^{1-\iota_{pm}}_m}\left(\frac{\Pi_{m,t+1}}{\Pi^{\iota_{pm}}_{m,t}\bar{\Pi}^{1-\iota_{pm}}_m}-1\right) \tag{58}$$

$$= \frac{\Pi_{m,t}\chi_{pm}}{\Pi^{\iota_{pm}}_{m,t-1}\bar{\Pi}^{1-\iota_{pm}}_m}\left(\frac{\Pi_{m,t}}{\Pi^{\iota_{pm}}_{m,t-1}\bar{\Pi}^{1-\iota_{pm}}_m}-1\right)+\vartheta_{m,t}\left[\begin{array}{c}1-\frac{\chi_{pm}}{2}\left(\frac{\Pi_{m,t}}{\Pi^{\iota_{pm}}_{m,t-1}\bar{\Pi}^{1-\iota_{pm}}_m}-1\right)^2\\ -\frac{P^*_t}{ner_t P_{m,t}}\end{array}\right]-1,$$

where $y_m = c_m + i_m$ represents import sales volumes. $P^*$ is the price of the foreign good which is procured by the importer and sold in domestic currency. $\chi_{pm} > 0$ measures the associated price adjustment cost and $\vartheta_m > 1$ is the demand elasticity for imports.

12. Goods market clearing:

$$y_t = c_{d,t} + i_{d,t} + y^*_{x,t} + \varepsilon_{es,t} + AC_{p,t} + AC_{w,t}, \tag{59}$$

where $y^*_x$ indicates export sales volumes. $\varepsilon_{es}$ is exogenous spending which includes government spending and changes in inventories. $AC_p$ and $AC_w$ are price and wage adjustment costs expressed in terms of the domestic good.

13. The foreign economy is closed and specified using laws of motions for output $(y^*)$, inflation $(\Pi^*)$ and interest rate $(R^*)$ :

$$(y^*_t)^{-1} = \mathbb{E}_t\left(y^*_{t+1}\right)^{-1}\beta^*\frac{R^*_t}{\Pi^*_{t+1}}, \tag{60}$$

$$\mathbb{E}_t\beta^*\frac{\lambda^*_{t+1}}{\lambda^*_t}\frac{y^*_{t+1}}{y^*_t}\frac{\Pi^*_{t+1}}{\bar{\Pi}^*}\chi^*\left(\frac{\Pi^*_{t+1}}{\bar{\Pi}^*}-1\right) = \frac{\Pi^*_t}{\bar{\Pi}^*}\chi^*\left(\frac{\Pi^*_t}{\bar{\Pi}^*}-1\right)+\bar{\vartheta}\left[1-\frac{\chi^*}{2}\left(\frac{\Pi^*_t}{\bar{\Pi}^*}-1\right)^2-y^*_t\right]-1, \tag{61}$$

and

$$\frac{R^*_t}{\bar{R}^*} = \left(\frac{R^*_{t-1}}{\bar{R}^*}\right)^{r_R}\left(\frac{\mathbb{E}_t\Pi^*_{t+1}}{\bar{\Pi}^*}\right)^{(1-r_R)r_\pi}\left(\frac{y^*_t}{\bar{y}^*}\right)^{(1-r_R)r_y}, \tag{62}$$

where the parameters are given the same values as their analogues in the small open economy.

# B Further Estimation Details and Results

As mentioned in Section 3, we use 15 series to estimate the log-linearised SOE model. We use 15 shocks to link the model to the observed data. 12 AR(1) structural shocks are embedded in the model: shocks to the loan markup $(\mu^L)$, deposit mark-down $(\mu^D)$, funding interest rate spread $(\tau^m)$, stable funding ratio $(\upsilon^{sfr})$, monetary policy $(\varepsilon_{mp})$, consumption discount factor $(\varepsilon_\beta)$, business investment $(\varepsilon_i)$, exogenous spending $(\varepsilon_{es})$, technology $(\varepsilon_{tfp})$, import price markup $(\mu_{pm})$, export price markup $(\mu_{px})$ and wage markup $(\mu_n)$. As in Smets and Wouters (2007), the shocks are rescaled to enter the estimation with a unit coefficient. In addition, we use 3 AR(1) measurement errors in the observation equations for loan growth $(me^{\Delta\ell})$, deposit growth $(me^{\Delta d})$ and bond growth $(me^{\Delta b})$. We use 1,000,000 iterations of the Random Walk Metropolis Hastings algorithm to simulate the posterior distribution and achieve an acceptance rate of about 22 percent. The first 500,000 draws are discarded. We monitor the convergence of the marginal posterior distributions using trace-plots, CUMSUM statistics as well as the partial means test as in Geweke (1999). The test statistics confirm that all parameter estimates converge. To reduce the autocorrelation between the draws, we retain only every $75^{th}$ iteration. Posterior parameter moments, impulse response functions and simulated moments of the endogenous variables are computed from 5000 parameter vectors randomly drawn from the thinned chain.

In Figure 5, we compare the volatilities of the data series used in the estimation with the analogous volatilities generated from the SOE model when parameters are set at values randomly drawn from the posterior distribution. The model captures the unconditional volatilities of the variables fairly well: the data moments lie within or very close to the 95% probability set generated from the model in most cases. The fit is particularly striking for export price inflation and the policy rate. On the downside, the model over-predicts the volatilities of CPI inflation and output growth, the former more so than the latter. We continue the validation exercise in Figure 6 which compares the autocorrelation functions of the observed variables with their model analogues. The data moments mostly lie within the probability bands generated by the model and the match is rather striking for the stable funding ratio, retail deposit and loan rates and export price inflation. The SOE model is only modestly successful in tracking the autocorrelation of the growth rates of the real and financial quantities. It does not capture the pattern of persistence observed in the data although the data moments are within the limits of the credibility bands from the model at most horizons.

Table 7 reports the unconditional volatility decomposition of selected variables in the banking sector and the real economy. The structural disturbances have been loosely classified into financial and real-economy shocks, the latter being further disaggregated into demand-type and supply-type shocks. A striking feature of the variance decomposition is that financial sector disturbances have little quantitative impact on the real economy variables such output, inflation, interest rate and aggregate demand.[27] In stark contrast, real-economy disturbances play a more prominent role in explaining the volatility of the banking sector variables. Financial shocks have little effect on the real economy because the external bond market is estimated to be very liquid, and because the effect on the loan rate of a rise in external funding costs is moderated by substitution toward domestic deposit funding and higher deposit spreads. In contrast, real disturbances have a substantial effect on financial variables. In particular, technology shocks and cost-push shocks to import and export prices and wages matter for fluctuations in the banking sector variables. These disturbances contribute more than half the volatility of the retail deposit and loan interest rates. The marginal utility of consumption is an important factor driving the household's decisions to borrow and to save. Interestingly, the banking sector shocks play a subdued role in determining the dynamics of the retail interest rates. The SFR and observed stable funding ratio are driven mostly by the exogenous component of the SFR rule.

[27] An exception is the funding spread shock which contributes roughly 18% of consumption volatility in the long run. The spread shock is the most persistent of all the estimated disturbances, and hence plays a prominent role in the asymptotic variance decomposition presented here. In the short-run impulse response analysis, we observe that the spread shock generates weaker consumption dynamics than one standard deviation impulses from other real-economy shocks.