Monetary policy in the presence of an occasionally binding borrowing constraint

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Abstract

We build a DSGE model of housing with a borrowing constraint which binds only occasionally and illustrate that shocks to monetary policy and loan-to-value ratios generate asymmetric macroeconomic dynamics. Volatilities generated by the model differs considerably from the case of a model with a perpetually-binding constraint and hence changes the welfare consequences of monetary policy.

1 Introduction

We investigate the impact of an occasionally binding borrowing constraint on macroeconomic volatility and monetary policy. We conceive of the borrowing constraint in our model as an approximation to a collateral constraint or loan-to-value restriction on household lending. Loan-to-value restrictions can arise endogenously in response to financial frictions, as in Townsend (1979) and Kiyotaki and Moore (1997) for example, or as a regulatory device motivated by macroprudential concerns. Our analysis is particularly motivated by these latter concerns.

As a general principle, monetary and macroprudential policy should be coordinated if each policy domain has consequences for the objectives of the other (Kamber et al., 2014a; Eichengreen et al., 2011).\textsuperscript{1} Yet the importance of coordination inherently depends on the overlapping conse-

\textsuperscript{1}This insight goes back to Tinbergen (1952, p. 28): “...the values of the instrument variables are dependent, generally speaking, on all the targets set and cannot be considered in isolation”.

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quences of the policy spheres under consideration. In this paper we focus on the consequences of the borrowing constraint for monetary policy. How does the borrowing constraint affect macroeconomic volatilities – the traditional concern of monetary policy – and how does the borrowing constraint impact the propagation of monetary policy? We extend the analysis by taking a preliminary look at optimal monetary policy in the presence of an occasionally binding borrowing constraint.

The empirical context for our analysis is the introduction of macroprudential policies in New Zealand. In August 2013, the governor of the Reserve Bank of New Zealand announced that a ‘speed-limit’ on housing lending by registered banks would be introduced on 1 October 2013. Banks were “required to restrict new residential mortgage lending at loan-to-value ratios (LVRs) of over 80 percent to no more than 10 percent of the dollar value of their new housing lending flows.” In other words, a regulatory constraint was imposed on the proportion of new lending that could be done at high LVRs.

New Zealand’s LVR policy was introduced in light of developments in the housing market. In 2012 and 2013 house price inflation in New Zealand steadily increased, reaching 10 percent (year-on-year) in December 2013. The increase in house prices was primarily driven by developments in Christchurch and Auckland – the latter accounting for approximately $\frac{1}{3}$ of New Zealand’s total population. While the increase in house prices in Christchurch was explicable given the extensive destruction of housing in the wake of the 2010 and 2011 earthquakes, the underlying driver of house prices in Auckland remained less obvious.

The growth in house prices was greatly in excess of consumer price inflation, and raised concerns that house buyers were over-extending themselves, with attendant risks to the financial system. Interest rates were at historically low levels, and the Reserve Bank was concerned that high-LVR borrowers might not be able to cope with the future interest rate increases that were anticipated as the economy recovered and as inflationary pressure increased. Throughout 2013 the proportion of bank lending to borrowers with relatively low deposits increased over time, raising concerns that a collapse in house prices might leave financial institutions – and in particular the registered banks which form the backbone of financial intermediation in New Zealand – with a material increase in non-performing loans. While New Zealand banks were well-capitalised, and were relatively unaffected by the global financial crisis and the sovereign debt crisis in Europe, policy-makers remained concerned that the comparatively rosy outlook could quickly reverse.

In response, the Reserve Bank of New Zealand began to investigate a range of alternative policies that might be used to target these risks to financial stability. While interest rates could have been increased, the relatively low consumer price inflation meant that the Reserve Bank had a preference for more targeted instruments that would, it was hoped, reduce financial risks with less collateral.

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damage to the rest of the economy. Consequently, the Bank developed a suite of macro prudential policies, and in March 2013 the Reserve Bank of New Zealand released a consultation document about the proposed policies. In August 2013, following consultative feedback, the Reserve Bank of New Zealand announced the LVR policy described above.

We adopt a fairly conventional dynamic stochastic general equilibrium (DSGE) methodology to understand the impact of a newly-introduced borrowing constraint. We develop a model built on the preferences and constraints of several types of agents, and estimate the parameters of the model using data from 1993Q3-2013Q4, just prior to the introduction of the LVR. We then introduce a borrowing constraint and re-optimise private agent’s behaviour in this new environment given their preferences and constraints. We then compute macroeconomic volatilities and investigate how the constraint affects the propagation of shocks, in order to understand how the monetary transmission mechanism is affected by the change in the policy environment. We colloquially refer to our borrowing constraint as an LVR, but we should emphasise that it does not perfectly mirror the ‘speed limit’ policy instituted by the Reserve Bank of New Zealand, since our borrowing constraint applies to all borrowing, and not just to the flow of new lending.

By estimating the model we derive a reasonable characterisation of the relative importance of different shocks. Shock volatilities are crucial for optimal rules, since the appropriate policy response to, say, a supply shock may be quite different to the optimal response to a demand shock. Quite different policy rules may be found to be optimal depending on which shocks are found to be the predominant drivers of the economy.

The macroprudential policy that we approximate forces us to extend conventional DSGE models in three dimensions. First, macroprudential policies are typically concerned with the stability of the financial system. We thus develop a model that has banks, which are responsible for intermediating credit. These banks also intermediate credit from abroad to our small debtor economy. Second, an essential element is to have some heterogeneity between agents to provide an underlying motive for credit. Like much of the literature, such as Iacoviello (2005), Iacoviello and Neri (2010) and Pariès et al. (2011) for example, we assume that there are patient and impatient agents. The patient agents end up as creditors and own all financial assets, while the impatient agents become debtors. Third, the specific macroprudential policy that we focus on is a constraint with respect to lending on housing. To accommodate this constraint, we formally model housing demand and supply, in a vein similar to Iacoviello (2005) and Iacoviello and Neri (2010). This framework endogenously determines the price of housing, which is central to the loan-to-value borrowing constraint.

Linearised DSGE models are routinely used to characterise macroeconomic volatilities and macroeconomic policies – particularly monetary policy. However, the application of DSGE models to macroprudential policies is sometimes criticised because of the assumption of linearity. In this paper we introduce occasionally binding borrowing constraints, which introduce substantive nonlinearities into the dynamics of the model: small shocks may have different effects to large
shocks; the effect of shocks may depend on the starting point; and shocks may have asymmetric
effects depending on whether they are positive or negative. Assuming that these constraints are
occasionally binding is more realistic than assuming they must always bind.

The impact of any constraint depends on whether it is tight (binding) or slack. In some cases
a constraint may be introduced that has no impact, as the optimal action is in the interior of
the feasible set, rather than on the boundary. In monetary policy circles ‘occasionally binding’
constraints have become prominent because of the imposition of the zero lower bound. Eggertsson
and Woodford (2003) and Jung et al. (2005), for example, apply a part-wise linear approach to
study optimal monetary in the presence of the lower bound.

For computational reasons, collateral constraints are often modelled as being always binding
(as in Iacoviello and Neri 2010 for example). However, in stochastic environments the optimal
action may vary over time depending on the sequence of shocks that occur. A constraint may thus
be only occasionally binding. For example, a consumer that experiences an adverse sequence of
income shocks may eventually reach their maximum ability to borrow. In a recent paper, Guerrieri
and Iacoviello (2014a) argue that LVRs can have profoundly non-linear effects on macroeconomic
dynamics precisely depending on whether the constraint on household borrowing is (or is not)
binding. In their analysis a particular confluence of shocks – such as positive shocks to house
prices – may occasionally cause the constraint to become slack.

Private sector behavior differs substantially depending on whether such a borrowing constraint
is binding. When a borrowing constraint binds, a private consumer or investor cannot use financial
markets to access real resources in the present by issuing claims to future income. Conversely, when
the constraint is slack, a private consumer may acquire real resources by borrowing against future
income. While borrowing-constrained households can alter their consumption and their hours
worked (abstracting from labour market imperfections), such households cannot transfer income
from the future to the present. A borrowing constraint thus profoundly alters the ‘margins of
adjustment’ available to private agents.

We focus on a borrowing constraint that is always present, but that does not always bind. Some policy-makers might argue that such a borrowing constraint is not representative of macro-
prudential policy because it is not time-varying or state-contingent.\footnote{International Monetary Fund (2011) identifies time-varying loan-to-value ratios, debt-to-income ratios, and
loan-to-income ratios as examples of macroprudential policies; time-constant analogues to these policies are not
discussed.} We regard the framework
developed here as an intermediate step, to help develop insight as to the effect of such a constraint.
Ultimately we wish to understand how time-varying macroprudential policies might impact mon-
etary policy, but such an analysis raises complex questions about the variables that should guide
macroprudential policy rules. Of course, whether macroprudential policies can be set in a time-
varying, state-contingent manner is much debated – see for example speeches by Stefan Gerlach,
Deputy Governor of the Central Bank of Ireland, and Daniel Tarullo, a member of the Board of Governors.\footnote{See \url{http://www.bis.org/review/r130920d.pdf} and \url{http://www.federalreserve.gov/newsevents/speech/tarullo20130920a.htm#f9}.}

Our main findings are as follows. We illustrate how the presence of the occasionally-binding constraint causes the model economy to respond asymmetrically to positive and negative monetary policy shocks. Following a monetary contraction, the model variants with occasionally- and perpetually-binding constraints behave identically. This is because house prices fall following the rise in the interest rate and the borrowing constraint is tightened in both cases. However, following a monetary expansion, rising house prices relaxes the borrowing constraint and the output boom is considerably muted, compared to the case of the perpetually-binding constraint. We then examine the consequences of an unexpected, permanent shift in the LVR restriction, given the estimated monetary policy rule. We demonstrate that a tightening of the LVR causes a severe decline in economic activity in model variants with occasionally- and perpetually-binding constraints. On the other hand, a reversal of the LVR restriction does not trigger an immediate change in the borrowing behaviour of agents in the model with the occasionally-binding constraint. The rise in economic activity is mild and gradual in this case.

We then calculate the optimal policy rules using an unconditional welfare criterion. We find that the optimal rule under the occasionally-binding constraint corrects the distortion due to the imperfect risk-sharing between borrowers and savers in the model and redistributes welfare from the saver to the borrower at the optimum. On the other hand, the model with the perpetually-binding collateral constraint yields exaggerated changes in welfare of the agents due to the excess volatility caused by the restriction of the linear solution method.

The rest of the paper is structured as follows. In section 2 we lay out the structure of the model and in Section 3 we discuss its estimation and properties. We then go on to discuss the properties of the model when an occasionally binding borrowing constraint is introduced. This constraint introduces nonlinearities into the dynamics of the model, in a manner discussed in more depth in Guerrieri and Iacoviello (2014a). Section 4 illustrates the macroeconomic response following positive and negative monetary policy shocks in the presence of an occasionally binding borrowing constraint and explores what happens when the borrowing constraint is tightened and then loosened. Section 5 then discusses our investigation of optimal policy. We focus on two dimensions – how strong should the interest rate response be to fluctuations in output and inflation? Lastly, section 6 concludes.
2 Model

The world consists of two countries, the home country being infinitesimally small when compared to the foreign country. The home country is labelled a small open economy (SOE). As in 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 real economy segment of the model is standard and along the lines of the empirical SOE model of Adolfson et al. (2007). Hence this section focuses on the housing and financial sectors, leaving the more conventional behavioural equations to the appendix.

Steady-state variables are indicated with an upper bar and without the time-period subscript \( t \) and for any variable \( z, \hat{z}_t \equiv \frac{\partial z_t}{\bar{z}} = \log \frac{z_t}{\bar{z}} \) indicates that the variable is presented as a logarithmic deviation from steady-state. \( E \) represents the conditional expectations operator. All the stochastic shock processes are indicated by \( \omega(z) \) and follow the law of motion \( \omega(z),t = \rho(z)\omega(z),t-1 + \sigma(z)\varepsilon_t \) where \( \varepsilon_t \sim \text{i.i.d.} \ N(0,1), \sigma(z) > 0 \) and \( \rho(z) \in [0,1) \).

2.1 Households

2.1.1 Patient households

The economy is populated by a unit measure of infinitely-lived patient households indexed by \( j \), who maximises the present discounted value of utility, described by the following expected utility function defined over consumption \( c \), housing stock \( h \) and labour supply \( n \)

\[
E_t \sum_{\tau=0}^{\infty} \beta^\tau \omega_{c,t+\tau} \left[ \log c_{t+\tau}(j) + \omega_{h,t+\tau} \xi_h \log h_{t+\tau}(j) - \xi_n \frac{(n_{t+\tau}(j))^{1+\phi_n}}{1+\phi_n} \right] \tag{1}
\]

\( \beta \in (0,1), \xi_h, \xi_n > 0, \phi_n \geq 0 \)

\( \phi_n \) is the inverse of the Frisch elasticity of labour while \( \xi_h \) and \( \xi_n \) determine the relative weights of housing and labour in utility. Importantly, the patient household’s discount factor \( \beta \) is assumed to be higher than that of the impatient household, i.e. it places a relatively smaller weight on current consumption in its consumption choice. As we will see later in subsection 3.3.2, the difference in the rates of intertemporal discounting between the two households plays a key role in the transmission of structural shocks. \( \omega_c \) is a shock that lowers the agent’s propensity to postpone consumption to the future and \( \omega_h \) is a housing demand shock which stimulates the intratemporal substitution between consumption and housing services.

The patient household’s period budget constraint is given by

\[
c_t(j) + \frac{S_t(j)}{P_{c,t}} + q_{h,t} \left[ n_t(j) - (1 - \delta_h)h_{t-1}(j) \right] + q_{k,t} \left[ k_t(j) - (1 - \delta_k)k_{t-1}(j) \right] \leq \frac{R_{k,t}}{P_{c,t}} k_{t-1}(j) + \left( \frac{W_{t}(j) - \Psi_{w,t}(j)}{P_{c,t}} \right) n_t(j) + \frac{R_{t-1}S_{t-1}(j)}{P_{c,t}} + \frac{D_{b,t}}{P_{c,t}} + \Omega_{f,t} \tag{2}
\]
where
\[ \Psi_{w,t}(j) = \frac{\kappa_w W_t}{2 P_{c,t}} \left( \frac{W_t(j)}{W_{t-1}(j)} \left( \frac{W_{t-1}}{W_{t-2}} \right)^{1/\tau_w} - 1 \right)^2 \] (3)
\[ \kappa_w > 0, \quad \tau_w \in [0, 1], \quad \delta_h, \delta_k \in [0, 1] \]

The patient household purchases the housing service \( h \) from the final housing service producers at the CPI-deflated price \( q_h \). \( \delta_h \) is the depreciation rate of the housing stock. The patient household also stores its savings in bank deposits \( S \) at a gross nominal return \( R \). As in Erceg et al. (2000), each household is a monopolistic supplier of specialised labour \( n(j) \) at the nominal wage rate \( W(j) \).

Perfectly competitive ‘employment agencies’ aggregate the specialised labour-varieties from the households into a homogenous labour input \( n \) using a constant elasticity of substitution (CES) technology where \( \nu > 1 \) determines the elasticity of substitution between labour varieties. The labour aggregate is then sold to the intermediate goods firms as an input for production. We also introduce nominal wage rigidities by stipulating that it is costly ‘a la Rotemberg (1982) to change wages and the convex cost function \( \Psi_w(\cdot) \) governs the degree of wage stickiness. \( D_b \) denotes the nominal dividends received from the bank while \( \Omega_f \) are the profits from firms. Finally, patient households purchase capital goods \( K \) from the final capital goods producers (see subsection 2.3.3) at the relative price \( q_k \) and rent them at the nominal rental rate of \( R_k \) to intermediate goods firms.

All nominal variables are deflated by the CPI represented by \( P_c \).

The patient household \( j \) chooses consumption, nominal wages, deposits, physical capital stock and housing stock to maximise the discounted expected utility function (1), subject to the budget constraint (2). In a symmetric equilibrium, the optimality conditions are given as

\[ c_t : \frac{\bar{c}_t}{c_t} = \lambda_t \] (4)
\[ W_t : E_t^{\beta} \frac{\lambda_t+1}{\lambda_t} \frac{n_{t+1}}{n_t} \frac{\pi_{w,t+1}^2}{\pi_{w,t}^2} \frac{\pi_{w,t+1}}{\pi_{w,t}} K_w \left( \frac{\pi_{w,t+1}}{\pi_{w,t}^2} - 1 \right) \] (5)
\[ = \frac{\pi_{w,t}}{\pi_{w,t-1}^{1-\tau_w}} K_w \left( \frac{\pi_{w,t}}{\pi_{w,t-1}^{1-\tau_w}} - 1 \right) + \nu \left[ 1 - \frac{\omega_{c,t} \xi_h n_{t+1} \sigma_n}{\lambda_t} \frac{P_{c,t}}{W_t} - \frac{\kappa_w}{2} \left( \frac{\pi_{w,t}}{\pi_{w,t-1}^{1-\tau_w}} - 1 \right)^2 \right] - 1 \]
\[ S_t : 1 = E_t^{\beta} \frac{\lambda_t+1}{\lambda_t} \frac{R_t}{\pi_{c,t+1}} \] (6)
\[ k_t : q_{k,t} = E_t^{\beta} \frac{\lambda_t+1}{\lambda_t} \frac{R_{k,t+1}}{P_{c,t+1}} + (1 - \delta_k) q_{k,t+1} \] (7)
\[ h_t : q_{h,t} = \omega_{c,t} \omega_{h,t} \xi_h \frac{\lambda_t}{\lambda_t h_t} + E_t^{\beta} \frac{\lambda_t+1}{\lambda_t} (1 - \delta_h) q_{h,t+1} \] (8)

Equation (4) expresses \( \lambda \) the marginal utility of income as an inverse function of consumption. In (5), nominal wage adjustment costs introduce a time-varying wedge between the real wage and the marginal rate of substitution between consumption and leisure. Equation (6) ties down
intertemporal changes in the marginal utility of income - and hence consumption - to the ex-ante real interest rate. Equation (7) equates for the marginal cost of acquiring business capital to the discounted expected marginal benefit of rental income and the price of the undepreciated capital stock in the next period. Finally, equation (8) determines the demand for housing. At the optimum, the marginal cost of acquiring housing services is balanced by the marginal utility derived from using the housing stock and discounted expected value of the undepreciated housing stock in the ensuing period. Note that in the remainder of this paper, we will also refer to the patient households as savers.

2.1.2 Impatient Households

Analogous to the patient household, the economy is populated by a unit measure of infinitely lived impatient households indexed by \( j \), who maximise the present discounted value of utility. Impatient households will also be referred to as borrowers in this paper. Their utility function is identical to that of the patient household, but is differentiated by a lower discount factor \( \beta' \). In addition, it is also assumed that the discount factor is less than that of banks (see subsection 2.2) to facilitate borrowing.

\[
E_t \sum_{\tau=0}^{\infty} (\beta')^\tau \omega_{c,t+\tau} \left[ \log c'_t^j(j) + \omega_{h,t+\tau} \xi_h \log h'_t^{j+\tau}(j) - \xi_n \left( n'_t(j) + 1 \right) \frac{1}{1 + \phi_n} \right] (9)
\]

The impatient households use income to consume, buy housing services and repay their borrowing from banks. Their incomes come from their wage \( W'_t \), new borrowing \( L'_t \) from banks. The period budget constraint is given by

\[
c'_t(j) + q_{h,t} [h'_t(j) - (1 - \delta_h)h'_{t-1}(j)] + \frac{R_{l,t-1}L'_{t-1}(j)}{P_{c,t}} \leq \left( \frac{W'_t(j)}{P_{c,t}} - \Psi'_{w,t}(j) \right) n'_t(j) + \frac{L'_t(j)}{P_{c,t}} (10)
\]

where \( L' \) is the nominal loan borrowed by the impatient household from the bank at the gross interest rate \( R_l \). Symmetric to the patient household, wage-setting is subject to quadratic adjustment costs \( \Psi'_{w,t}(j) \).

As in Iacoviello (2005), the impatient household’s capacity to borrow is restricted by a collateral constraint. The macroprudential authority limits the borrower’s access to loans to a fixed proportion of the ex-ante discounted value of the following period’s housing stock, by imposing an LVR \( \mu' \) on the collateral constraint. Specifically,

\[
\frac{L'_t(j)}{P_{c,t}} \leq \mu' E_t \frac{q_{h,t+1} h'_t(j)}{R_{l,t+1}/\pi_{c,t+1}} (11)
\]

Taking prices as given, the impatient household \( j \) chooses consumption, wages, loans and housing to maximise the discounted lifetime utility function (9) subject to the budget constraint (10) and the borrowing constraint (11). Let \( \lambda' \) be the marginal utility of real income at time \( t \), and \( \lambda' \gamma' \) is the Lagrangian multiplier on the borrowing constraint. The optimality conditions for consumption
and wages simply mirror that of the patient household and hence are not exhibited here. The key point of departure from the case of the patient household, lies in the interaction between the tightness of the collateral constraint and the demand for housing. This is evident from the optimality conditions for housing and loans.

\[ h_t' : q_{h,t} = \omega_c t \omega_h t \xi_h t \lambda_t^{1+1} + \gamma'_t \lambda_t^{1+1} (1 - \delta_h) q_{h,t+1} + \gamma'_t E_t q_{h,t+1} R_{t,t} / \pi_{c,t+1} \] (12)

\[ L_t' : 1 - \gamma'_t = E_t \beta_t^{1+1} R_{t,t} / \pi_{c,t+1} \] (13)

A binding collateral constraint, i.e. \( \gamma' > 0 \), generates additional benefits from consuming housing services in equation (12). Accumulating housing stock generates more collateral to borrow against in the following period. Observe that when the collateral constraint does not bind, i.e. \( \gamma' = 0 \), this channel disappears and the optimality condition is identical in structure to that of the patient household. The consumption Euler equation (13) of the impatient household is also altered by the presence of the occasionally-binding constraint. When the constraint binds, the impatient household borrows less than it would under a non-binding constraint. This implies a lower level of consumption. Later, in Section 5, we examine the welfare implications of monetary policy when the collateral constraint binds only occasionally.

### 2.2 Banks

Banks are owned by the patient households and maximise the present discounted value of dividend payouts.

\[ \max E_t \sum_{\tau=0}^{\infty} \beta^{1+\tau} D_{b,t+\tau} (j) / P_{c,t+\tau} \] (14)

where \( \beta' < \beta_b < \beta \) is the banks’ subjective discount factor. The \( j^{th} \) bank’s period budget constraint is given by

\[ \frac{D_{b,t} (j)}{P_{c,t}} + \frac{R_{t-1} S_{t-1} (j)}{P_{c,t}} + \frac{\Phi_{t-1} R_{t-1} S_{t-1} (j)}{e \lambda_t P_{c,t}} + \frac{L_t (j)}{P_{c,t}} \leq \frac{S_t (j)}{P_{c,t}} + \frac{S_e (j)}{e \lambda_t P_{c,t}} + \frac{R_{t-1} L_{t-1} (j)}{P_{c,t}} \] (15)

In addition to receiving deposits \( S \) from the patient households, banks borrows abroad in foreign-currency denominated bonds \( S_e \) at the gross nominal rate \( R_e \). \( e \) is the nominal exchange rate, expressing the value of foreign currency in terms of one unit of home currency, so that a rise indicates an appreciation of the home currency. As in Alpanda et al. (2014), \( \Phi \) is the international risk premium given by

\[ \Phi = \exp \left[ -\Phi_{nfa} \left( NFA_t - NFA \right) - \Phi_e \left( \frac{e_t}{E_t e_{t+1}} - 1 \right) \right], \Phi_{nfa} > 0, \Phi_e \in [0, 1) \]

where \( NFA_t = \frac{S_e}{e_t e_{t+1}} \). \( \Phi_{nfa} \) ensures that the incomplete markets model is stationary (see Schmitt-Grohé and Uribe, 2003) and \( \Phi_e \) captures the persistence in exchange rate dynamics.
The bank is also subject to a capital requirement constraint of the form

$$\frac{L_t(j) - S_t(j) - S_t^*(j)}{L_t(j)} = 1 - \mu_{b,t}$$

(16)

where: \( \mu_{b,t} = \mu_{b,t-1} \left( \frac{L_t}{P_{d,t} y_{d,t}} \right)^{b_l(1-b_l)}, \ b_l > 0, \ b_l \in [0, 1) \)

The bank capital required in order to support the optimal leverage level chosen by the bank is assumed to be acquired at no extra costs, either by retained earnings or equity injections by the bank owners. In addition, there are regulatory capital requirements that stipulate that banks must have a capital to loans ratio greater than or equal to \( 1 - \mu_b \). Further, we assume that \( \mu_b \) is negatively related to the leverage level of the economy. \( b_l \) is an elasticity parameter which makes the capital requirement \( 1 - \mu_b \) higher when the economy is higher leveraged. \( b_b \) captures the inertia in the dynamics of the capital requirement.

The bank \( j \) takes prices as given and maximises the discounted expected dividends (14) with respect to deposits, foreign-currency bonds and loans, subject to the budget constraint (15) and the capital requirement constraint (16). Let \( \gamma_b \) be the Lagrangian multiplier on the capital requirement constraint.

\[
\begin{align*}
S_t : & \quad 1 - \gamma_{b,t} = E_t \beta_t \frac{\lambda_{t+1}}{\lambda_t} \frac{R_t}{\pi_{c,t+1}} \\
S_t^* : & \quad 1 - \gamma_{b,t} = E_t \beta_t \frac{\lambda_{t+1}}{\lambda_t} \frac{\epsilon_t}{\epsilon_{t+1} \pi_{c,t+1}} \Phi_t \\
L_t' : & \quad 1 - \mu_{b,t} \gamma_{b,t} = E_t \beta_t \frac{\lambda_{t+1}}{\lambda_t} \frac{R_{l,t}}{\pi_{c,t+1}} 
\end{align*}
\]

(17)  (18)  (19)

Combining the optimality conditions for deposits in equation (17) and loans in equation (19) and log-linearising, we obtain the relationship between the capital requirement and the lending spread.

$$\hat{R}_{l,t} - \hat{R}_t = \frac{-\bar{\mu}_b \hat{\gamma}_b}{(1 - \bar{\mu}_b \hat{\gamma}_b)} \hat{\mu}_{b,t} + \frac{\bar{\gamma}_b (1 - \bar{\mu}_b)}{(1 - \bar{\gamma}_b) (1 - \bar{\mu}_b \bar{\gamma}_b)} \hat{\gamma}_{b,t}$$

(20)

When the capital requirement is more stringent, manifested by a fall in \( \hat{\mu}_{b,t} \) and a rise in \( \hat{\gamma}_{b,t} \), the lending spread widens and limits the borrowing of the impatient agents. In the absence of the capital requirement, impatient households borrow infinitely in response to even transient shocks which leads to a unit root in the model. This is akin to the non-stationarity problem originating from the open-economy dimension of the model which is resolved by using the international risk premium \( \Phi_{nfa} \) associated with the acquisition of net foreign assets.
2.3 Production

2.3.1 Intermediate goods firms

There is a continuum of monopolistically competitive firms indexed by \( j \in [0, 1] \) specialising in the production of a unique intermediate variety \( y(j) \) using the following technology

\[
y_t(j) = \omega_y k_{t-1}(j)^{\alpha_k} [n_t(j)^{\alpha_n} n'_t(j)^{1-\alpha_n}]^{1-\alpha_k}, \quad \alpha_k, \alpha_n \in [0, 1] \tag{21}
\]

\( n \) and \( n' \) are the labour bundles from the patient and impatient households respectively, aggregated by the employment agencies and sold to the intermediate goods firm. \( \alpha_n \) governs the share of patient households in the aggregate demand for labour. We further assume that the labour force is immobile between countries. \( k \) represents the capital stock rented from the patient households and \( \alpha_k \) is the share of capital in production. Finally, the production function is stimulated by the technology shock \( \omega_y \).

The rest of the production structure of the SOE is very standard and similar to that of Adolfson et al. (2007). The domestic firms sell the intermediate good to a final good producer who uses a continuum of these goods in production. In addition to the domestic firms, we model importing as well as exporting firms. The importing firms transform a homogenous good, bought in the world market, into a differentiated import good, which they sell to the final goods producer. On the other hand, exporting firms buy the domestic final good and differentiate it by brand naming. Each exporting firm is thus 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 programmes for domestic goods, imports and exports. In addition, prices are assumed to be sticky in the currency of the buyer so that exchange rate passthrough is imperfect for both import and export prices. We list the relevant equations in the appendix.

2.3.2 Aggregation

Perfectly competitive firms produce final goods for consumption, business investment, and housing by aggregating domestic and imported goods.

\[
Z_t = \left( 1 - m_z \right)^{\frac{1}{\eta}} Z_{d,t}^{\frac{\eta-1}{\eta}} + m_z Z_{m,t}^{\frac{\eta-1}{\eta}}, \quad m_z \in [0, 1], \quad \eta > 0 \tag{22}
\]

where \( Z \in \{C, IK, IH\} \). \( Z_d \) and \( Z_m \) are in turn Dixit-Stiglitz aggregates of intermediate varieties with \( \nu > 1 \) governing the elasticity of substitution between the individual varieties. The analogous price indices of the final goods are given by

\[
P_{z,t} = \left( 1 - m_z \right) P_{d,t}^{1-\eta} + m_z P_{m,t}^{1-\eta} \tag{23}
\]
and the demand functions for the domestic and imported component of each aggregate is given as

\[ Z_{d,t} = (1 - m_z) \left( \frac{P_{d,t}}{P_{z,t}} \right)^{-\eta} Z_t, \quad Z_{m,t} = m_z \left( \frac{P_{m,t}}{P_{z,t}} \right)^{-\eta} Z_t \]  

(24)

### 2.3.3 Business and housing capital producers

Business capital producers are perfectly competitive. These firms purchase the undepreciated physical capital from patient households at a relative price of \( q_k \) and the new capital investment goods from aggregator firms at a relative price of \( q_{ik} \) and produce the capital stock to be carried over to the next period. This production is subject to adjustment costs in investment, and is described by the following law of motion

\[ K_t = \omega_{ik,t} I_K \left[ 1 - \frac{\kappa_{ik}}{2} \left( \frac{IK_t}{IK_{t-1}} - 1 \right)^2 \right] + (1 - \delta_k) K_{t-1}, \quad \delta_k \in [0, 1], \quad \kappa_{ik} > 0 \]  

(25)

After capital production, the end-of-period installed capital stock is sold back to patient household at the consumption-based price of \( q_k \). The capital producer chooses investment to maximise profits.

\[ \max_{IK_t} E_t \sum_{\tau=0}^{\infty} \beta^\tau \frac{\lambda_{t+\tau}}{\lambda_t} \left\{ q_{k,t+\tau} \omega_{ik,t+\tau} \left[ 1 - \frac{\kappa_{ik}}{2} \left( \frac{IK_{t+\tau}}{IK_{t+\tau-1}} - 1 \right)^2 \right] - q_{ik,t+\tau} \right\} IK_{t+\tau} \]

Optimality implies

\[ \frac{q_{ik,t}}{q_{k,t} \omega_{ik,t}} = 1 - \frac{\kappa_{ik}}{2} \left( \frac{IK_t}{IK_{t-1}} - 1 \right)^2 - \frac{IK_t}{IK_{t-1}} \kappa_{ik} \left( \frac{IK_t}{IK_{t-1}} - 1 \right) \]  

+ \[ E_t \beta^\tau \frac{\lambda_{t+\tau}}{\lambda_t} q_{k,t+\tau} \omega_{ik,t+\tau} \left( \frac{IK_{t+\tau}}{IK_t} \right)^2 \kappa_{ik} \left( \frac{IK_{t+\tau}}{IK_t} - 1 \right) \]  

Equation (26) is a supply curve for business investment goods. For a given path of expected investment growth, current investment responds positively to an increase of the relative price of investment to that of physical capital, with the response decreasing in the investment adjustment cost. Housing investment and house prices are similarly related since housing capital producers are modelled analogously to business capital producers. They transform housing investment goods \( IH \) into housing services \( H \) by using the following technology

\[ H_t = \omega_{ih,t} IH_t \left[ 1 - \frac{\kappa_{ih}}{2} \left( \frac{IH_t}{IH_{t-1}} - 1 \right)^2 \right] + (1 - \delta_h) H_{t-1}, \quad \delta_h \in [0, 1], \quad \kappa_{ih} > 0 \]  

(27)

where \( \omega_{ih} \) is the investment-specific technology shock affecting housing. The supply curve for housing is given as

\[ \frac{q_{ih,t}}{q_{h,t} \omega_{ih,t}} = 1 - \frac{\kappa_{ih}}{2} \left( \frac{IH_t}{IH_{t-1}} - 1 \right)^2 - \frac{IH_t}{IH_{t-1}} \kappa_{ih} \left( \frac{IH_t}{IH_{t-1}} - 1 \right) \]  

+ \[ E_t \beta^\tau \frac{\lambda_{t+\tau}}{\lambda_t} q_{h,t+\tau} \omega_{ih,t+\tau} \left( \frac{IH_{t+\tau}}{IH_t} \right)^2 \kappa_{ih} \left( \frac{IH_{t+\tau}}{IH_t} - 1 \right) \]  

(28)

Observe that, just as in the case of business investment, the relative prices of housing investment and installed capital would be the same in the absence of adjustment costs.
2.4 Monetary policy

Given the domestic equilibrium conditions and the structure of the foreign economy (see appendix A.1), the model is closed by specifying that monetary policy is set according to the Taylor-type rule. The nominal interest rate is influenced by past interest rates and also responds to the current CPI inflation rate and output growth. \( r \in (0, 1] \) measures the inertia in the policy rate, \( r_\pi > 1 \) is the elasticity of the policy rate to inflation while \( r_{\Delta y} \geq 0 \) is the analogue for output growth. Finally, \( \omega_r \) may be interpreted as the unsystematic, exogenous component in the conduct of policy.

\[
\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{r_r} \left[ \left( \frac{\pi_{c,t}}{\bar{\pi}_c} \right)^{r_\pi} \left( \frac{y_t}{y_{t-1}} \right)^{r_{\Delta y}} \right]^{1-r_r} \exp \omega_{r,t} \tag{29}
\]

3 Estimation

In this section, we obtain empirically-plausible values for the model parameters and shock volatilities which form the basis of the normative analysis that follows later. To this end, we estimate the SOE model using data for New Zealand. Since we estimate the model using historical data predating the introduction of the loan-to-value restrictions, the borrowing constraint does not play a role in the estimated model. Specifically, in the estimated version of the model, we assume that the constraint in (11) is slack and consequently the associated multiplier \( \gamma' \) is eliminated from the optimality conditions in (12) and (13).

3.1 Data and methodology

The SOE model is estimated employing 9 quarterly macroeconomic time series. The sample begins in 1993 Q4 right after the inflation-targeting regime was put in place, and ends in 2014 Q3 before the Reserve Bank introduced restrictions in high loan-to-value lending. We use per capita growth rates of household lending, output, consumption along with residential and business investment. The remaining data series are: the 90-day bank bill rate, which closely tracks the policy rate; CPI inflation; house price inflation; and the spread between a floating first mortgage rate for new customers and the 90-day rate. Table 1 presents a more detailed description of the observed time series and the observation equations which link them to the theoretical model.

We apply the Bayesian estimation methodology discussed by An and Schorfheide (2007). In a nutshell, the Bayesian paradigm facilitates the combination of 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 also provides further technical details on the estimation methodology in subsection A.2.
3.2 Priors

A subset of the structural parameters, crucial for the model’s steady-state are given dogmatic priors at calibrated values. Table 2 lists all the parameters that are calibrated. The time-discount factors of patient and impatient households (\(\beta, \beta'\)) are set to 0.993 and 0.987 to match an annualised 3 percent real risk-free interest rate, and a spread on household loans of 228 basis points, the latter based on data for the effective mortgage rate. The discount factor for banks is set to 0.94 to match a steady-state bank capital requirement ratio of 0.9.

We rely on New Zealand national accounts data, to set the long-run shares of residential and business investment relative to output at 5.5 percent and 17.3 percent respectively, while housing-to-output and capital-to-output ratios are fixed at 10.5 and 2.83 on an annualised basis. Based on these ratios, we fix the annual depreciation rates for housing and capital stocks (\(\delta_h, \delta_k\)), at 2.2 percent and 6.11 percent respectively. The shares of imported goods in final-goods production for consumption, business and residential investment (\(m_c, m_{ik}, m_{ih}\)) are set to 0.2, 0.67 and 0.1 respectively, which roughly correspond with the long-run ratios observed in the data. The level parameters for housing in the utility function (\(\xi_h, \xi'_h\)) are calibrated to ensure that the total housing value is 10.5 times annual GDP, and impatient households own about 33 percent of the total housing.\(^5\) On the other hand, the level parameters for labour supply (\(\xi_n, \xi'_n\)) are calibrated to ensure that labor supply is equal to 1 at the steady-state for both types of households. The share of capital in domestic production, \(\alpha_k\), is set to 0.3, implying an income share of labour equal to 70%. We set the wage share of patient households \(\alpha_n\) to 0.67. The elasticity of the capital requirement to the loan-to-output ratio is set at 200 in order to target a long-run household debt-to-output ratio of 0.98 which is close to the data. The remaining calibrated values are drawn from Kamber et al. (2014b).

An overview of the priors used for our estimated parameters can be found in Table 3. The adjustment cost parameters \(\kappa_{ih}\) and \(\kappa_{ik}\) specific to residential and business investment are given Normal priors centered at 5, which span the region covered by similar cost parameters estimated in the literature.\(^6\) A Beta prior of mean 0.5 is chosen for the degree of smoothing in the capital requirement rule. Other real-economy parameters such as those pertaining to the monetary policy rule, price-setting for domestic sales as well as shock persistence and volatility are given priors similar to those of Kamber et al. (2014b).

\(^5\)The best proxy for impatient households is the share of households that have a mortgage. The latest estimate of this figure from the June 2013 New Zealand Household Economic Survey is around 33%. See Table 11 in http://www.stats.govt.nz/%7emedia/Statistics/Browse%20for%20stats/HouseholdEconomicSurvey/HOTPYeJun13/HES-jun13year-tables.xls

\(^6\)See Smets and Wouters (2007) for an estimate of 5.7 for the United States and Adolfson et al. (2007) for an estimate of 7.7 for the eurozone.
3.3 Estimation results

3.3.1 Posteriors and model fit

Table 3 also presents the moments of the marginal posterior distributions of the estimated parameters. The housing and business investment adjustment cost parameters are each estimated at about 8, considerably distinct from the priors that we imposed. These values are in the ballpark of previous estimates of aggregate investment adjustment costs found in Smets and Wouters (2007) and Adolfson et al. (2007) for the US and eurozone. However, the data is less informative on the smoothing parameter for the capital requirement, perhaps due to the fact that the requirement is not an observed series in the estimation. The remaining parameters pertaining to the monetary policy rule and the domestic sales Phillips curve are well identified and the estimates are very close to those found by Kamber et al. (2014b).

In Figure 1, 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. The model captures the volatilities of the policy rate, business investment growth and the lending spread fairly well. However, it mildly over-predicts the volatilities of the remaining observables with the standard deviations in the data, lying slightly outside the 95 percent probability bands of the analogous moments generated from the model. Figure 2 compares the autocorrelation functions of the observables with their analogues generated by the model. The theoretical model matches the persistence in the data reasonably well for most variables, as the data moments mostly lie within the probability bands generated by the model. The SOE model does particularly well in tracking the autocorrelation of the policy rate and the lending spread. However, in contrast, the model generates no persistence in house price inflation while in the data this variable is fairly persistent. This is not surprising because DSGE models of housing interpret the house price as a purely forward-looking asset price characterised by little inertia. The model performs relatively better in generating persistence in loan growth although we observe that the autocorrelation in the data is systematically higher.

3.3.2 Selected impulse responses

We now examine the model dynamics triggered by structural shocks to monetary policy, technology and housing demand. In each case, we consider a unit standard deviation positive innovation to the shock process.\(^7\)

**Monetary policy shock** Figure 3 presents the impulse responses induced by an exogenous stimulus to monetary policy. Recall that this version of the model imposes no borrowing constraint

\(^7\)The impulse response functions of other shocks are available on request.
and hence the macroprudential policy instrument is inactive. For this reason, the dynamics are not dissimilar to standard open-economy models. The interest rate increase is accompanied by a fall in CPI inflation, output, consumption and business investment and an appreciation of the real exchange rate. The lending spread increases due to the capital requirement imposed on the banks and this suppresses the demand for loans from the impatient households. In the housing market, the expensive credit conditions result in a fall in housing investment and the house price.

**Technology shock**  The dynamics triggered by a technology shock are presented in Figure 4. The improvement in technological progress elevates output and the accompanying wealth effect raises the consumption profile of the savers and borrowers. Inflation falls and the policy rate follows suit due to the Taylor-rule. The fall in prices induces a real depreciation of the currency. Lower interest rates reflect in a higher demand for credit which in turn stimulates investment in both the business and housing sectors. House prices rise reflecting the rise in housing demand.

**Housing demand shock**  In Figure 5, we present the dynamics that follow an exogenous increase in the demand for housing. This shock stimulates the housing market by elevating both housing investment and prices. Since the shock is positioned in the model as a stimulus on the intratemporal substitution between consumption and housing expenditures, consumption of both savers and borrowers are crowded out. A similar crowding-out effect is observed in business investment. The reactions of output, CPI inflation and the policy rate are statistically insignificant initially but positive in the ensuing periods, the latter two variables contributing to an appreciation of the real exchange rate.

4 Model solution with an occasionally binding constraint

Our purpose is to evaluate the welfare-maximising monetary policy in the empirically appealing case of the collateral constraint in equation (11) does not necessarily bind in all periods. However, the presence of this non-linearity makes it impossible to solve the SOE model with standard rational expectation solution algorithms. On the other hand, given that our model has more than 30 state variables, conventional projection methods are computationally infeasible. For these reasons, we make use of the OccBin toolbox developed by Guerrieri and Iacoviello (2014b), which implements a piecewise-linear approximation method to solve DSGE models with occasionally-binding constraints. This toolbox has been applied to models with borrowing constraints, the zero-lower-bound on the nominal interest rate, and asymmetric wage rigidities. The toolbox can solve for the rational expectations solution with unknown durations of each regime. It uses a guess-and-verify procedure to generate time-varying policy functions depending on the expected
duration of regimes at each period.\textsuperscript{8}

We now evaluate the influence of the occasionally-binding constraint on the economy under two distinct changes in the policy environment. We first consider the dynamics triggered by a monetary expansion or contraction and later analyse the scenario when the LVR policy is tightened and subsequently relaxed. In both scenarios, we emphasise the asymmetry in the response of key variables.

4.1 Asymmetric response to a monetary policy shock

In Figure 6, we illustrate how the presence of the occasionally-binding constraint causes the model economy to respond asymmetrically to positive and negative monetary policy shocks. The dashed blue lines indicate the results from the model with a collateral constraint which binds perpetually, while the thicker red lines represent the analogues from the version with an occasionally-binding constraint. In the top panel, we find that the dynamics in key variables in the two model variants are identical to each other: an elevated policy rate depresses prices, output and loans, irrespective of whether the constraint binds occasionally or perpetually. The lowering of the house price in response to the monetary tightening causes the collateral constraint to bind in the model variant with the occasionally-binding constraint. Hence the two model variants behave identically during recessions.

In the bottom panel, where we examine a negative monetary policy shock, it can be seen that the dynamics in the perpetually-binding model are simply the mirror image of those observed in the top panel. However, in the model with the occasionally-binding constraint the dynamics are more muted in absolute terms than the corresponding positive monetary shock. This is especially true of the real quantities, such as output and loans. The key difference between the two set-ups is that when the constraint is allowed to bind occasionally, the observed LVR (not exhibited) is endogenised and varies with the business cycle. The endogenity of the LVR is reflected in the asymmetric cyclical behaviour of the real variables. During downturns, the constraint is forced to bind and variables behave as in the case of the model with the perpetually-binding constraint (top panel, Figure 6). However, the constraint is not binding during booms (bottom panel, Figure 6) and the model with the occasionally-binding constraint predicts more modest expansions compared to the perpetually-binding case.

We now harness all the shocks in the structural estimation to stochastically simulate the two model variants. In Figure 7, we plot the simulated path of selected variables in the two cases. With the occasionally-binding constraint the observed LVR is endogenised and moves with the business cycle. We indicate the periods in which the constraint binds with grey bars. Importantly, the asymmetric dynamics over the cycle results in different predictions for volatilities. In Table

\textsuperscript{8}For more details about the solution method, see Guerrieri and Iacoviello (2014b).
we compare the volatilities of output and inflation predicted from the two variants. When the steady-state LVR is set lower at 0.7, we observe little difference in the volatilities generated by the two variants. However, when the LVR is set equal to 0.9, the variant with the perpetually-binding constraint generates higher volatilities than the variant with the occasionally-binding constraint, particularly for output. This has important implications for optimal monetary policy since the measurement of social welfare typically hinges on the volatilities of output and inflation. In the following section, we offer a formal analysis of policy implications of the occasionally-binding constraint.

4.2 Consequences of a tightening or loosening of the LVR

In this section we first consider the impact of a permanent decrease in the LVR, reducing the amount that borrowers can borrow against the value of housing. We then explore what happens when this decrease in the LVR is reversed. Both of these changes are treated as permanent, unanticipated shocks. The goal is to understand how a change in the LVR is transmitted through the macroeconomy, conditional on the monetary policy stance. We continue to assume that the central bank sets the policy rate according to the estimated monetary policy rule.

We first consider a decrease in the LVR from 0.9 to 0.8 of the value of housing. The value of 0.9 is taken as a benchmark LVR, as might be applied by financial institutions themselves. The consequences of the decreased LVR are stark and severe. On impact, borrowers are forced to reduce their consumption by 40 percent relative to steady-state to accommodate the required change in borrowing. Since the model allows for no secondary, unregulated sources of finance, the borrowing constraint necessitates severe adjustment to non-housing consumption by borrowers.

The behaviour and adjustment of consumption for borrowers and savers is quite different. Savers who are unconstrained by the borrowing constraint, have access to foreign savings and can therefore smooth their own consumption, their housing investment, and their business investment through time. Thus, quite unlike the borrowers who are subject to the binding constraint, savers adjust to their change in circumstances very slowly. Interestingly, by preventing mutually beneficial gains between borrowers and savers, the savers actually slowly reduce their consumption, and their investment in both physical and housing capital. Housing investment drops by about 4 percent relative to steady state, business investment by about 1 percent relative to steady state, and consumption reduces by about 3 percent relative to steady-state far out in the future.

Since the steady-state consumption by savers is about twice that of borrowers, the latter gets much less weightage in the log-linearised dynamics of aggregate consumption. Consequently, the reduction in aggregate consumption is more modest, at about 12 percent relative to steady-state. The reduction in consumption, which is partially offset by an increase in net exports (not exhibited), results in a decline in output of approximately 6 percent from steady-state. The impact effect on inflation of this permanent LVR shock is around -0.6 percent in annualised terms, but inflation
returns to about steady-state levels a year later. Reflecting both the decline in output and inflation, the estimated policy rule depresses the interest rate, but then two quarters later it is returned to a level akin to the steady state.

Nominal house prices are relatively unaffected by the change in the borrowing constraint. The lack of movement in house prices reflects that the house purchases by the patient savers, who are unconstrained by the borrowing constraint, and impatient borrowers are almost perfectly inversely correlated. The symmetry between the housing demand of the two agent types is only broken by the impact of housing investment, which changes the stock of available houses. Interestingly, the impatients borrowers actually increase their housing ownership following the decreased LVR. Borrowers relaxing the borrowing constraint by increasing their equity stake in houses as well as by reducing the stock of outstanding loans by around 7 percent on impact. While the real stock of loans decreases as the LVR is introduced, the change quickly reverses.

The LVR restriction as modelled applies to all borrowing by the impatient agents. Thus, the consequences are considerably more severe than the policy actually instituted in New Zealand. The policy that was introduced in 2013 only applied to ‘new’ lending, rather than existing loans. Our LVR policy might be thought of as an average LVR, with the actual policy representing a more marginal concept. Thus, it seems likely that the 10 percent decline in the average LVR is probably an order of magnitude larger than the policy put into place. Because the constraint is always binding following this permanent shock to the LVR, the qualitative results would be the same in response to a scaled-down version of the shock investigated here.

We now consider what happens to the economy when the LVR is permanently and unanticipatedly relaxed from 0.8 back to 0.9. Due to the occasionally-binding solution of the model, we can illustrate that the effect of relaxing the LVR is not symmetric to the initial tightening.

Even though the LVR requirement changes immediately, the observed LVR itself takes much longer to return to its original level. House prices which were only slightly below their steady-state value gradually increase back towards the steady-state. Somewhat surprisingly, the relaxation of the borrowing constraint leads to only a slow increase in real lending. Borrowers’ consumption increases by 2 percent on impact once the borrowing constraint is relaxed and then falls back below steady-state after about 20 quarters. Saver consumption only increases gradually, mirroring the slow adjustment during the original decline in the LVR. Again, the consumption adjustment from borrowers and lenders is quite asymmetric.

Borrowers’ elevated housing ownership levels are gradually reduced through time, and after about 10 years are back near their steady-state levels. Conversely savers’ ownership of housing takes much longer to return to steady-state. Housing investment also increases towards steady-state. The adjustment in business investment is even more mild and protracted. The level of output increase on impact but is relatively unaffected by the relaxation of the borrowing constraint. Similarly, the rate of inflation changes very little once the LVR is relaxed, in part because there is
a small increase in the policy interest rate. Overall, the macroeconomic consequences of relaxing the LVR appear to be quite muted in this model.

5 Optimal Monetary Policy

To design and set policy rules policy-makers require some metric to be able to rank alternatives. Given our micro-foundations, we evaluate different policy rules using the utility functions of the (domestic) patient and impatient agents. Our policy analysis aims to improve our understanding of the effects of the borrowing constraint on monetary policy rules.

There are three elements that affect welfare: 1) the long-run outlook for the steady state; 2) the transition from any starting point towards the steady state; and 3) the variability experienced around that transition, reflecting the influence of stochastic shocks during the transition period. When a model is approximated to first order, only the first two elements can be identified. Conventionally, second or higher order approximations are required to identify the influence of stochastic variation on welfare. Higher order approximations enable one to understand how the expected paths of variables (such as welfare) differ from the paths that would arise in a deterministic environment. Monetary policy rules do not affect the welfare-relevant components of the steady state, but do affect both the transition back towards steady state and the response of the economy to stochastic disturbances.

Given a quadratic approximation to a model it is possible to use conventional perturbation techniques to identify optimal policies, as in Schmitt-Grohé and Uribe (2004) and Kim et al. (2008) for example, or one can use the approach pioneered by Rotemberg and Woodford (1997), Sutherland (2002), Woodford (2003), Benigno and Woodford (2005), and Benigno and Woodford (2008) to evaluate policies using a linear-quadratic approximation. However, both these approaches are inapplicable with occasionally binding constraints, because required assumptions about differentiability are not satisfied. These differentiability problems arise as constraints switch from being binding to non-binding (or vice-versa).

We attempt to circumvent this problem by relying on repeated simulations of (pseudo) data to approximate the types of stochastic paths that might be experienced by agents given the application of a given policy rule. Given the asymmetries implied by occasionally binding constraints the expected and deterministic transition paths will not perfectly coincide. Nevertheless, our approximation neglects quadratic terms for the model constraints, and conceivably these terms could affect welfare given that our steady state is not efficient and we do not employ a subsidy to offset steady state distortions, such as those arising from monopoly power. See Woodford (2003) for a discussion of these issues in the linear-quadratic context, and Heer and Maussner (2009) for a nice heuristic explanation.

We measure the welfare of the agents in the economy based on the discounted expected lifetime
utility using simulated data. Due to the heterogeneity of agent types, we first calculate the welfare of representative patient and impatient agents as

\[ v = E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, h_t, n_t) \]  

\[ v' = E_0 \sum_{t=0}^{\infty} (\beta')^t U(c'_t, h'_t, n'_t) \]

where \( v \) and \( v' \) denote the welfare of the patient household (saver) and impatient household (borrower), respectively. As in Lambertini et al. (2013), we then calculate social welfare as a weighted average of the welfare of two types of agents as follows

\[ V \equiv (1 - \beta) v + (1 - \beta') v' \]

where the weights are determined by subjective discount factors of two kinds of agents. These weights generate the same level of welfare for any given level of constant consumption streams. We also calculate the relative welfare loss between policies in percentage terms of life-time consumption as follows\(^9\)

\[ V_B - V_A = \ln(1 - \Lambda) + \frac{\bar{\beta}}{1 - \beta} \ln(1 - \Lambda) \]

where \( V_A \) and \( V_B \) denote the welfare level under policy rule \( A \) and \( B \), respectively, and \( \Lambda \) is the fraction of life-time consumption that households under regime \( A \) would be willing to sacrifice, leaving them indifferent between policy regimes \( A \) and \( B \). \( \bar{\beta} \) is the social discount factor that is the average of the discount factors of savers and borrowers.

Following Schmitt-Grohé and Uribe (2004), we focus on ‘operational’ Taylor rules. Schmitt-Grohé and Uribe consider a Taylor rule to be operation if it is based on observable variables and, secondly, generates a locally unique rational expectations equilibrium.\(^10\) An operational rule is ‘optimal’ when it yields a higher level of welfare than other rules under consideration.

We focus on two dimensions of the monetary policy rule: i) the response of the policy interest rate to inflation and ii) the response of the interest rate to output growth. These two dimensions are relevant for at least two reasons. First, savers and borrowers are both exposed to inflation risks, due to imperfect risk sharing. This imperfect risk sharing provides the central bank with an additional motive to stabilise inflation. Second, we conjecture that monetary policy may need to respond more vigorously to output movements when private agents are subject to a borrowing constraint. This is because impatient (borrower) agents cannot use financial markets to smooth

\(^9\)For the derivation of this equation, see Schmitt-Grohé and Uribe (2004).

\(^10\)Schmitt-Grohé and Uribe (2004) also require the operational rule to satisfy the zero-lower-bound condition of the nominal interest rate. This involves imposing a second occasionally binding constraint. Imposing another occasionally binding constraint is technically feasible, but computational intensive. We check nonnegativity of the nominal interest rate after each simulation. We find that, given the shocks we use in the optimal simple rule analysis, all interest rates are positive.
their demand for goods and services when the borrowing constraint binds. Such a constraint forces households to reduce consumption and work excessively hard during ‘bad times’, whereas it would be desirable for monetary policy to help agents to smooth both consumption and labour effort through time.

Our welfare analysis is based on stochastic simulations of the model using the piecewise linear solution method discussed earlier in Section 4.\textsuperscript{11} We maximise the objective function in (32) by pursuing a coarse grid-search for the inflation ($r_\pi$) and output growth ($r_{\Delta y}$) parameters in a fairly conventional Taylor rule, keeping all other parameters fixed at their estimated values. Given a specific pair of Taylor rule parameters, we then supply a vector time series of exogenous shocks and simulate the vector of endogenous variables for 500 periods, $\{x_t\}_{t=1}^{500}$. We repeat this simulation exercise 200 times. Averaging across replications we have a sample approximation to the expected values $E_0(x_t)$ for $t = 1, \ldots, 500$, in equations (30) and (31). We repeat this exercise for each candidate policy rule, using the same underlying random shocks via a seeded random number generator.\textsuperscript{12}

Our grid of output coefficients is the following: $r_{\Delta y} \in [-1, 3]$ with a step-size of 0.5. And we explore the following candidate parameter responses to inflation: $r_\pi \in \{1.1, 1.89, 2.5, 3.0\}$. Our estimated policy parameters, while not explicitly represented by one of the nodes of the grid, lie roughly in the centre of this parameter space.

In Table 5, we report the results of the welfare-analysis. First we present the welfare measures implied by the estimated rule as a benchmark to evaluate the relative performance of the other rules. In the second row, we present the policy rule which maximises social welfare under the occasionally-binding collateral constraint. Observe that the social welfare improves very marginally from the case of the estimated rule; an increment of only 0.002 percent of the lifetime consumption stream. However, optimal monetary policy has a redistributive effect on the welfare of the two types of agents in the model. While the welfare of the saver decreases by roughly 1%, the borrower’s welfare increases by 0.7%. Recall that the model does not allow for complete risk-sharing between the two agents and hence optimal monetary policy plays a role in achieving a better welfare distribution between the agents in the economy. The last row of the table reports the optimal rule under a perpetually-binding contraint. The welfare gains of the saver are quite substantial at 9.8% while the borrower experiences a comparably large decline of 11.6%. Note that the exaggerated changes in the welfare distribution can be associated to the excess volatility that the perpetually-binding constraint induces in the economy (as was emphasised in section 4).

\textsuperscript{11}As acknowledged by Guerrieri and Iacoviello (2014b), the piecewise linear solution method does not take future shocks into account, therefore this approach is not able to capture the welfare consequences arising from precautionary saving behaviour.

\textsuperscript{12}Simulating data for this sample length and for this number of replications is time consuming, taking roughly 16 – 17 hours on a standard desktop for a single policy rule, though that time could be reduced by properly parallelising the code.
Surprisingly, both optimal rules imply a negative unit coefficient on output growth. This value is of course rather perturbing since it says that when output growth is high then interest rates should be low and vice-versa. A potential explanation for this peculiar result is due to the exclusion of house prices as a covariate in the policy rules. Several shocks in the models imply a negative correlation between house price inflation and output growth. Therefore, the negative coefficient on output growth could reflect a positive reaction of the interest rate to house price inflation.

6 Conclusion and directions for future research

In this paper we developed an open economy model with an occasionally binding borrowing constraint for a class of impatient agents. The borrowing constraint is endogenously determined, and depends on the collateral value of housing assets held by borrowers. The occasionally binding nature of the constraint introduces substantial asymmetry into macroeconomics dynamics. When the constraint binds, any reduction in the borrowing constraint enforces deleveraging, but positive shocks that slacken the borrowing constraint do not necessarily prompt a symmetric expansion of borrowing. This asymmetry stands in stark contrast with models that adopt permanently binding constraints.

Using this model we explore the consequences of the borrowing constraint for macroeconomic quantities such as output, inflation, consumption, and house prices. The borrowing constraint has markedly different consequences for borrowers and lenders. We illustrate that a unilateral change in the borrowing constraint forces massive deleveraging for borrowing agents with substantial consequences for borrower consumption, yet has only a modest impact on the consumption of savers. The profile of adjustment is quite different for the two agents, with borrowing constrained agents adjusting rapidly, and lending agents smoothing their adjustment through time using financial markets. When the borrowing constraint is relaxed, once again the resulting dynamics are asymmetric and the economy as a whole adjusts slowly over time.

We conducted a preliminary investigation of optimal policy when the economy is subject to an occasionally binding borrowing constraint. We investigate a coarse grid of possible Taylor rules, exploring the response to output growth and inflation. We find that the optimal rule under the occasionally-binding constraint corrects the distortion due to the imperfect risk-sharing between borrowers and savers in the model and redistributes welfare from the saver to the borrower at the optimum. The optimal policy rule implies that there should be a muted response to inflation, and that the response to output should be procyclical, which could be due to the exclusion of house prices in the Taylor rule.

The model includes a financial intermediation channel from abroad, which we do not discuss at any great length in this paper. Understanding constraints on this intermediation channel is an area that we wish to investigate further. Likewise, the borrowing constraint is of a set-and-forget
variety, and macroprudential policy-makers often emphasise that such policies should be conducted in a time-varying manner, reflecting cyclical developments. This too is an avenue that we wish to investigate further in future work.

A Appendix

A.1 Other equilibrium conditions

Here we list the equilibrium conditions which were omitted from the main text.

1. Real marginal cost

\[ rm_{d,t} = MC_t/P_{d,t} = \chi_{mc} \left( R_{k,t}/P_{d,t} \right)^{\alpha_k} \left( W_t/P_{d,t} \right)^{\alpha_n(1-\alpha_k)} \left( W_t'/P_{d,t} \right)^{(1-\alpha_n)(1-\alpha_k)} \]

where \( \chi_{mc} = \alpha_k(1-\alpha_k)^{-(1-\alpha_k)} - \alpha_n(1-\alpha_k)(1-\alpha_n)^{-(1-\alpha_n)(1-\alpha_k)} \)

2. Domestic sales price-setting

\[
E_t^\beta \lambda_{t+1} \sum \frac{\pi_{d,t+1}^y t+1}{\pi_{d,t+1}^y t} \kappa_{pd} \left( \frac{\pi_{d,t+1}^y t+1}{\pi_{d,t+1}^y t} - 1 \right) = \frac{\pi_{d,t}^y t}{\pi_{d,t-1}^y t} \kappa_{pd} \left( \frac{\pi_{d,t}^y t}{\pi_{d,t-1}^y t} - 1 \right) + \nu \left[ 1 - \frac{\kappa_{pd}}{2} \left( \frac{\pi_{d,t}^y t}{\pi_{d,t-1}^y t} - 1 \right)^2 - rm_{d,t} \right] - 1
\]

\( \kappa_{pd} > 0 \) measures the associated price adjustment cost and \( t_{pd} \in [0,1] \) measures the degree of price indexation. Note that we assume that the elasticities of substitution between goods varieties for domestic, export or import sales are the same as the elasticity of substitution between labour varieties and they are jointly represented by \( \nu > 1 \).

3. Export sales price-setting

\[
E_t^\beta \lambda_{t+1} \sum \frac{\pi_{x,t+1}^y t+1}{\pi_{x,t+1}^y t} \kappa_{px} \left( \frac{\pi_{x,t+1}^y t+1}{\pi_{x,t}^y t} - 1 \right) = \frac{\pi_{x,t}^y t}{\pi_{x,t-1}^y t} \kappa_{px} \left( \frac{\pi_{x,t}^y t}{\pi_{x,t-1}^y t} - 1 \right) + \nu \left[ 1 - \frac{\kappa_{px}}{2} \left( \frac{\pi_{x,t}^y t}{\pi_{x,t-1}^y t} - 1 \right)^2 - P_{d,t} \right] - 1
\]

\( P_x \) is the foreign-currency price set by the exporter for the domestic good. \( \kappa_{px} > 0 \) moderates the price adjustment cost and \( t_{px} \in [0,1] \) measures the degree of price indexation.

4. Import sales price-setting

\[
E_t^\beta \lambda_{t+1} \sum \frac{\pi_{m,t+1}^y t+1}{\pi_{m,t+1}^y t} \kappa_{pm} \left( \frac{\pi_{m,t+1}^y t+1}{\pi_{m,t}^y t} - 1 \right) = \frac{\pi_{m,t}^y t}{\pi_{m,t-1}^y t} \kappa_{pm} \left( \frac{\pi_{m,t}^y t}{\pi_{m,t-1}^y t} - 1 \right) + \nu \left[ 1 - \frac{\kappa_{pm}}{2} \left( \frac{\pi_{m,t}^y t}{\pi_{m,t-1}^y t} - 1 \right)^2 - P_{t}^*/e_t \right] - 1
\]
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. \( \kappa_{pm} > 0 \) measures the associated price adjustment cost and \( \iota_{pm} \) represents the degree of indexation.

5. Intermediate goods market clearing

\[
y_t = c_{d,t} + ik_{d,t} + ih_{d,t} + y^*_{x,t} + \Theta_t
\]

where \( y^*_{x} \) indicates export sales volumes. \( \Theta \) includes all nominal and real convex adjustment costs expressed in terms of the domestic good. In the linearised version of the model, we add an exogenous spending shock \( \omega_{es} \) to the goods market clearing condition.

6. Final consumption and housing goods and labour market clearing

\[
C_t = c_t + c'_t \\
IH_t = ih_t + ih'_t \\
N_t = n_t + n'_t
\]

7. Balance of payments (in foreign currency)

\[
-(S^*_{t} - \Phi_{t-1}R^*_{t-1}S^*_{t-1}) = P_{x,t}y_{x,t} - (c_{m,t} + ik_{m,t} + ih_{m,t})
\]

8. Export demand

\[
y_{x,t} = \left( \frac{P_{x,t}}{P^*_t} \right)^{-\eta_x} y^*_t
\]

where \( y^* \) is foreign output.

9. Foreign economy (log-linearised)

\[
\pi^*_t = \beta E_t \tilde{\pi}^*_t + \frac{\nu - 1}{\kappa_{pd}} \tilde{y}^*_t \\
E_t \tilde{y}^*_{t+1} = \tilde{y}^*_t + \tilde{R}^*_t - E_t \tilde{\pi}^*_{t+1} \\
\tilde{R}^*_t = r_r \tilde{R}^*_{t-1} + (1 - r_r) \left[ r_y \tilde{\pi}^*_t + r_{\Delta y} (\tilde{y}^*_t - \tilde{y}^*_{t-1}) \right]
\]

\( \pi^* \) and \( R^* \) are the foreign inflation and interest rate respectively.

### A.2 Estimation Details

A requirement for a likelihood-based estimation exercise is that there are at least as many shocks as there are observable data series. In the log-linearised version of the SOE model, we embed structural shocks to the consumption discount-factor (\( \omega_c \)), technology (\( \omega_y \)), housing demand (\( \omega_h \)), housing supply (\( \omega_{ih} \)), business investment (\( \omega_{ik} \)), exogenous spending (\( \omega_{es} \)) and monetary policy (\( \omega_r \)). As in Smets and Wouters (2007), the shocks are rescaled to enter the estimation with a
unit coefficient. In addition to these 7 structural shocks, we use 2 measurement errors in the observation equations for credit growth and the interest rate spread to link the model to the data. In sum, we have 9 shocks to match the 9 observable time series. The estimation of the SOE model is implemented in the Matlab-based toolbox Dynare Version 4.4.2 (see Adjemian et al., 2011). We use 1,000,000 iterations of the Random Walk Metropolis Hastings algorithm to simulate the posterior distribution and achieve an acceptance rates 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 75th 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.

References

URL http://ideas.repec.org/p/cpm/dynare/001.html


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URL http://www.jstor.org/stable/2297284


URL http://ideas.repec.org/a/eee/inecon/v61y2003i1p163-185.html


B Figures
Figure 1: Posterior Distributions of the Volatilities of Model Variables

Note: The model is simulated for 1080 periods for each of 5000 parameter vectors randomly drawn from the posterior. Only the last 80 periods, i.e. equivalent to the sample size used in our estimation, are used to compute the standard deviations of each variable. Each subplot presented above compares the distribution of the volatilities, to the volatility measured in the observed time series.
Figure 2: Autocorrelation of the Model Variables

Note: The model is simulated for 1080 periods for each of 5000 parameter vectors randomly drawn from the posterior. Only the last 80 periods, i.e. equivalent to the sample size used in our estimation, are used to compute the autocorrelations of each variable. Each subplot presented above compares the distribution of the model autocorrelations, to the analogues measured in the observed time series.
Figure 3: Dynamics triggered by a 1 S.D. Monetary Policy Shock

Note: IRFs are computed from 5000 parameter vectors randomly drawn from the posterior. Each subplot presents the percentiles of the distribution of IRFs. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.
Figure 4: Dynamics triggered by a 1 S.D. Technology Shock

Note: IRFs are computed from 5000 parameter vectors randomly drawn from the posterior. Each subplot presents the percentiles of the distribution of IRFs.

A rise in the exchange rate indicates an appreciation of the New Zealand dollar.
Figure 5: Dynamics triggered by a 1 S.D. Housing Demand Shock

Note: IRFs are computed from 5000 parameter vectors randomly drawn from the posterior. Each subplot presents the percentiles of the distribution of IRFs. A rise in the exchange rate indicates an appreciation of the New Zealand dollar.
Figure 6: Comparing IRFs Triggered by Positive and Negative Monetary Policy Shocks

Note: The shock size is fixed at 2 standard deviations in this illustrative example. The steady-state LVR ratio is set at 0.90 in both models.
Figure 6: Comparing Stochastic Simulations from Models with Binding and Occasionally-binding Constraints

Note: The shaded areas indicate the periods when the constraint binds. The steady-state LVR ratio is set at 0.90 in both models.
Figure 8: The Consequences of a Permanent Tightening of the LVR

Note: The LVR is kept at 90% for just below 3 years and then tightened to 80% permanently. Parameters are set at the posterior mode and other shocks are deactivated.
Figure 9: The Consequences of a Permanent Loosening of the LVR

Note: The LVR is loosened from 80% to 90% permanently. Parameters are set at the posterior mode and other shocks are deactivated.
C Tables
### Table 1: Data Transformation

<table>
<thead>
<tr>
<th>Description</th>
<th>Mnemonic</th>
<th>RBNZ FSIS ID</th>
<th>Transformation</th>
<th>Model Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working age population</td>
<td>pop</td>
<td>HLFS.Q.L07G001.ns</td>
<td>$- \Delta \log (c_t/pop_t) - \mu_1$</td>
<td>$- \Delta \hat{C}_t$</td>
</tr>
<tr>
<td>Real consumption (sa)</td>
<td>c</td>
<td>GDE.Q.EC1.rs</td>
<td>$100 \Delta \log (c_t/pop_t) - \mu_1$</td>
<td>$\Delta \hat{C}_t$</td>
</tr>
<tr>
<td>Real residential investment (sa)</td>
<td>ih</td>
<td>GDE.Q.EI291.rs</td>
<td>$100 \Delta \log (ih_t/pop_t) - \mu_2$</td>
<td>$\Delta \hat{H}_t$</td>
</tr>
<tr>
<td>Real private business investment (sa)</td>
<td>ik</td>
<td>GDE.Q.EI295.rs</td>
<td>$100 \Delta \log (ik_t/pop_t) - \mu_3$</td>
<td>$\Delta \hat{K}_t$</td>
</tr>
<tr>
<td>Real gross domestic product (b)</td>
<td>gdp</td>
<td>GDP06.Q.QT0.rs</td>
<td>$100 \Delta \log (gdp_t/pop_t) - \mu_4$</td>
<td>$\Delta \hat{y}_{d,t}$</td>
</tr>
<tr>
<td>Nominal household loans (c)</td>
<td>l</td>
<td>CRD.MOA301</td>
<td>$100 \Delta \log (l_t/pop_t) - \mu_5$</td>
<td>$\Delta \hat{L}<em>t + \omega</em>{l,t}^{me}$</td>
</tr>
<tr>
<td>Target inflation CPI measure</td>
<td>cpi</td>
<td>CPI.Q.ZS30.ia</td>
<td>$100 \Delta \log cpi_t - \mu_6$</td>
<td>$\pi_{c,t}$</td>
</tr>
<tr>
<td>Nominal house prices (sa)</td>
<td>qh</td>
<td>HPI.Q.H01T0.is</td>
<td>$100 \Delta \log qh_t - \mu_7$</td>
<td>$\Delta \hat{q}<em>{h,t} + \pi</em>{c,t}$</td>
</tr>
<tr>
<td>3 month bank bill</td>
<td>i90</td>
<td>INM.QB03.N</td>
<td>$i_{90} - \mu_8$</td>
<td>$4\hat{R}_t$</td>
</tr>
<tr>
<td>Floating mortgage interest rate</td>
<td>rh</td>
<td>INR.MII61.F</td>
<td>$r_{h} - i_{90} - \mu_9$</td>
<td>$4\left(\hat{R}_{t,t} - \hat{R}<em>t\right) + \omega</em>{rfr,t}^{me}$</td>
</tr>
</tbody>
</table>

Note: $\Delta$ is the temporal difference operator. The parameters $\mu_1$ through $\mu_9$ are the sample means of the respective time-series. $\omega_{l,t}^{me}$ and $\omega_{rfr,t}^{me}$ are AR(1) measurement errors.
Table 2: Calibrated Parameters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>{\beta, \beta^', \beta_h}</td>
<td>Discount factors of patient agents, impatient agents and bank</td>
<td>{0.993, 0.987, 0.94}</td>
</tr>
<tr>
<td>{\delta_k, \delta_h}</td>
<td>Depreciation of business capital and housing capital</td>
<td>{0.0153, 0.0055}</td>
</tr>
<tr>
<td>{\alpha_k, \alpha_n}</td>
<td>Share of production of capital and patient agent’s labour</td>
<td>{0.33, 0.67}</td>
</tr>
<tr>
<td>{m_c, m_{ik}, m_{ih}}</td>
<td>Import-share of consumption, business and housing investment</td>
<td>{0.20, 0.67, 0.10}</td>
</tr>
<tr>
<td>\eta</td>
<td>Elasticity of substitution between home and foreign goods</td>
<td>0.52</td>
</tr>
<tr>
<td>\nu</td>
<td>Elasticity of substitution between intermediate goods or labour varieties</td>
<td>11</td>
</tr>
<tr>
<td>\beta_l</td>
<td>Capital requirement elasticity to loans/output</td>
<td>200</td>
</tr>
<tr>
<td>{\xi_h, \xi^'_h}</td>
<td>Weight on utility of housing</td>
<td>{0.50, 0.75}</td>
</tr>
<tr>
<td>{\xi_n, \xi^'_n}</td>
<td>Weight on disutility of labour</td>
<td>{2.11, 2.11}</td>
</tr>
<tr>
<td>\phi_n</td>
<td>Inverse of Frisch elasticity of labour</td>
<td>1.39</td>
</tr>
<tr>
<td>\pi_e</td>
<td>Trend CPI inflation</td>
<td>1.005</td>
</tr>
<tr>
<td>{\kappa_w, \kappa_e}</td>
<td>Nominal wage adjustment cost and indexation</td>
<td>{249, 0.33}</td>
</tr>
<tr>
<td>{\kappa_{pm}, \kappa_{pm}}</td>
<td>Nominal import price adjustment cost and indexation</td>
<td>{769, 0.39}</td>
</tr>
<tr>
<td>{\kappa_{px}, \kappa_{px}}</td>
<td>Nominal export price adjustment cost and indexation</td>
<td>{229, 0.49}</td>
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<tr>
<td>\Phi</td>
<td>Steady-state international risk premium (Gross)</td>
<td>1.0025</td>
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<tr>
<td>\Phi_{n,fa}</td>
<td>Elasticity of risk premium to net foreign assets</td>
<td>0.003</td>
</tr>
<tr>
<td>\Phi_e</td>
<td>Smoothing parameter in exchange rate equation</td>
<td>0.25</td>
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</tbody>
</table>

Note: Other steady-state parameters are derived from the restrictions of the model. These are detailed in the online technical appendix that accompanies the paper.
Table 3: Parameter Estimates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Prior (P1, P2)</th>
<th>Mode</th>
<th>Mean</th>
<th>2.5%ile</th>
<th>97.5%ile</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa_{ih}$</td>
<td>Housing investment adjustment cost</td>
<td>N(5, 2)</td>
<td>7.95</td>
<td>8.12</td>
<td>5.10</td>
<td>11.31</td>
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<tr>
<td>$\kappa_{ik}$</td>
<td>Business investment adjustment cost</td>
<td>N(5, 2)</td>
<td>7.83</td>
<td>7.94</td>
<td>4.81</td>
<td>11.23</td>
</tr>
<tr>
<td>$b_b$</td>
<td>Capital requirement smoothing</td>
<td>B(0.50, 0.10)</td>
<td>0.50</td>
<td>0.50</td>
<td>0.30</td>
<td>0.70</td>
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<tr>
<td>$\kappa_{pd}$</td>
<td>Domestic sales price adjustment cost</td>
<td>N(205, 25)</td>
<td>212.06</td>
<td>212.20</td>
<td>165.98</td>
<td>260.63</td>
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<tr>
<td>$\lambda_{pd}$</td>
<td>Domestic sales price indexation</td>
<td>B(0.50, 0.10)</td>
<td>0.31</td>
<td>0.33</td>
<td>0.19</td>
<td>0.50</td>
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<tr>
<td>$r_r$</td>
<td>Policy rate smoothing</td>
<td>B(0.75, 0.05)</td>
<td>0.82</td>
<td>0.82</td>
<td>0.78</td>
<td>0.86</td>
</tr>
<tr>
<td>$r_{\pi}$</td>
<td>Policy rate response to CPI inflation</td>
<td>G(2, 0.10)</td>
<td>1.90</td>
<td>1.90</td>
<td>1.72</td>
<td>2.10</td>
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<tr>
<td>$r_{\Delta y}$</td>
<td>Policy rate response to output growth</td>
<td>N(0.15, 0.10)</td>
<td>0.32</td>
<td>0.32</td>
<td>0.16</td>
<td>0.49</td>
</tr>
<tr>
<td>$\rho_{ih}$</td>
<td>AR(1) Housing investment shock</td>
<td>B(0.50, 0.10)</td>
<td>0.53</td>
<td>0.52</td>
<td>0.36</td>
<td>0.67</td>
</tr>
<tr>
<td>$\rho_{ik}$</td>
<td>AR(1) Business investment shock</td>
<td>B(0.50, 0.10)</td>
<td>0.31</td>
<td>0.31</td>
<td>0.19</td>
<td>0.46</td>
</tr>
<tr>
<td>$\rho_{h}$</td>
<td>AR(1) Housing demand shock</td>
<td>B(0.50, 0.10)</td>
<td>0.86</td>
<td>0.86</td>
<td>0.81</td>
<td>0.89</td>
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<tr>
<td>$\rho_{y}$</td>
<td>AR(1) Technology shock</td>
<td>B(0.50, 0.10)</td>
<td>0.51</td>
<td>0.49</td>
<td>0.33</td>
<td>0.65</td>
</tr>
<tr>
<td>$\rho_{c}$</td>
<td>AR(1) Consumption impatience shock</td>
<td>B(0.50, 0.10)</td>
<td>0.82</td>
<td>0.81</td>
<td>0.74</td>
<td>0.88</td>
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<tr>
<td>$\rho_{es}$</td>
<td>AR(1) Exogenous spending shock</td>
<td>B(0.50, 0.10)</td>
<td>0.84</td>
<td>0.84</td>
<td>0.76</td>
<td>0.90</td>
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<tr>
<td>$\rho_{r}$</td>
<td>AR(1) Monetary policy shock</td>
<td>B(0.50, 0.10)</td>
<td>0.23</td>
<td>0.23</td>
<td>0.15</td>
<td>0.33</td>
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<tr>
<td>$\rho_{me}$</td>
<td>AR(1) Measurement error (Loan growth)</td>
<td>B(0.50, 0.10)</td>
<td>0.48</td>
<td>0.48</td>
<td>0.33</td>
<td>0.62</td>
</tr>
<tr>
<td>$\rho_{me}$</td>
<td>AR(1) Measurement error (Mortgage spread)</td>
<td>B(0.50, 0.10)</td>
<td>0.82</td>
<td>0.80</td>
<td>0.71</td>
<td>0.88</td>
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<tr>
<td>$\sigma_{ih}$</td>
<td>S.D. Housing investment shock</td>
<td>IG(0.10, 2)</td>
<td>4.28</td>
<td>4.43</td>
<td>3.30</td>
<td>5.76</td>
</tr>
<tr>
<td>$\sigma_{ik}$</td>
<td>S.D. Business investment shock</td>
<td>IG(0.10, 2)</td>
<td>5.09</td>
<td>5.17</td>
<td>4.30</td>
<td>6.19</td>
</tr>
<tr>
<td>$\sigma_{h}$</td>
<td>S.D. Housing demand shock</td>
<td>IG(0.10, 2)</td>
<td>0.46</td>
<td>0.49</td>
<td>0.35</td>
<td>0.69</td>
</tr>
<tr>
<td>$\sigma_{y}$</td>
<td>S.D. Technology shock</td>
<td>IG(0.10, 2)</td>
<td>0.27</td>
<td>0.29</td>
<td>0.22</td>
<td>0.38</td>
</tr>
<tr>
<td>$\sigma_{c}$</td>
<td>S.D. Consumption impatience shock</td>
<td>IG(0.10, 2)</td>
<td>0.27</td>
<td>0.30</td>
<td>0.20</td>
<td>0.43</td>
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<tr>
<td>$\sigma_{es}$</td>
<td>S.D. Exogenous spending shock</td>
<td>IG(0.10, 2)</td>
<td>0.67</td>
<td>0.69</td>
<td>0.59</td>
<td>0.81</td>
</tr>
<tr>
<td>$\sigma_{r}$</td>
<td>S.D. Monetary policy shock</td>
<td>IG(0.10, 2)</td>
<td>0.19</td>
<td>0.20</td>
<td>0.17</td>
<td>0.24</td>
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<tr>
<td>$\sigma_{me}$</td>
<td>S.D. Measurement error (Loan growth)</td>
<td>IG(0.10, 2)</td>
<td>1.08</td>
<td>1.10</td>
<td>0.95</td>
<td>1.29</td>
</tr>
<tr>
<td>$\sigma_{me}$</td>
<td>S.D. Measurement error (Mortgage spread)</td>
<td>IG(0.10, 2)</td>
<td>0.23</td>
<td>0.23</td>
<td>0.20</td>
<td>0.27</td>
</tr>
</tbody>
</table>

**Note:** $G \equiv$ Gamma, $B \equiv$ Beta, $IG \equiv$ Inverse Gamma and $N \equiv$ Normal distribution. $P1 \equiv$ Mean and $P2 \equiv$ Standard Deviation for all distributions. These moments are computed from 5000 random draws from the simulated posterior distribution.
Table 4: Comparing Moments from the Perpetually- and Occasionally-binding Models

<table>
<thead>
<tr>
<th>Loan-to-Value Ratio</th>
<th>Binding Frequency</th>
<th>Output S.D. (%)</th>
<th>CPI Inflation S.D. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occasional</td>
<td>Perpetual</td>
<td>Occasional</td>
</tr>
<tr>
<td>0.70</td>
<td>12%</td>
<td>100%</td>
<td>0.75</td>
</tr>
<tr>
<td>0.90</td>
<td>10.4%</td>
<td>100%</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Note: The two model variants are simulated for 1000 periods with the parameters set at the posterior mode.
Table 5: Welfare Evaluations Under Optimised Rules

<table>
<thead>
<tr>
<th>Taylor Rules</th>
<th>Welfare Level (Gain in terms of consumption)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Saver</td>
</tr>
<tr>
<td>(1) Estimated Taylor rule</td>
<td>-84.83 (1)</td>
</tr>
<tr>
<td>( \hat{R}<em>t = 0.80 \hat{R}</em>{t-1} + 0.2 (1.89 \hat{\pi}_{c,t} + 0.32 \Delta \hat{y}_t) )</td>
<td></td>
</tr>
<tr>
<td>(2) Optimal Taylor rule (occasionally-binding)</td>
<td>-85.88 (1.04%)</td>
</tr>
<tr>
<td>( \hat{R}<em>t = 0.80 \hat{R}</em>{t-1} + 0.2 (1.1 \hat{\pi}_{c,t} - \Delta \hat{y}_t) )</td>
<td></td>
</tr>
<tr>
<td>(3) Optimal Taylor Rule (perpetually-binding)</td>
<td>-75.4 (9.8%)</td>
</tr>
<tr>
<td>( \hat{R}<em>t = 0.80 \hat{R}</em>{t-1} + 0.2 (3 \hat{\pi}_{c,t} - \Delta \hat{y}_t) )</td>
<td></td>
</tr>
</tbody>
</table>