The Liquidity Premium of Government Debt under a Floor System of Monetary Policy

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Abstract

Investors derive non-pecuniary benefits from the liquidity of short-term government debt. However, the central bank affects the supply of reserves, which work as close substitutes. This paper contends that a floor system of monetary policy, where the central bank attains its monetary policy rate target without altering the reserves supply, allows for untangling the role of fiscal and monetary policies in determining the liquidity premium on short-term government debt. Focusing on New Zealand's implementation of a floor system in July 2006, findings indicate that government debt issuance consistently reduces the liquidity premium, irrespective of its substitutability with other liquid assets. Additionally, increasing the interest on reserves (IOR) within a floor system diminishes the government's fiscal capacity by lowering the liquidity premium. Finally, under a floor system, the cyclical dynamics of the liquidity premium hinder the transmission from IOR to the intertemporal rate, impacting monetary policy efficacy.

Key words: liquidity premium, monetary policy, treasury bills.

JEL codes: E43, E52, G12.

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1 Introduction

Investors derive non-pecuniary benefits from the liquidity of short-term government debt, rendering public debt a near-money asset that carries a liquidity premium, often referred to as a "convenience yield." This phenomenon increases the price of government bonds, thereby expanding the government's fiscal capacity. However, the central bank exerts influence over the supply of reserves and private deposits, which function as close liquid substitutes. This raises questions about what determines the liquidity premium on government debt. Can the premium vanish with excessive government borrowing, or can the monetary policy rate establish a positive liquidity premium irrespective of government borrowing? The existing empirical literature on convenience yields presents conflicting answers to these inquiries. Some findings indicate a negative impact of a larger debt supply (Krishnamurthy and Vissing Jorgensen, 2012; Greenwood, Hanson, and Stein, 2015), while others suggest that the liquidity premium of government debt is solely contingent on the supply of liquid private deposits, influenced by the level of the monetary policy rate (Nagel, 2016; Drechsler, Savov, and Schnabl, 2017).

This paper contends that one explanation for these divergent results is the high collinearity between the supply of short-term government debt and its substitutes (reserves and checkable deposits) during the business cycle, particularly under a corridor (or scarce reserves) system of monetary policy. Central banks raising the monetary policy rate and draining reserves from banks coincide with the government issuing fewer short-term T-Bills, making the identification of each effect difficult. Instances where the central bank attains its monetary policy rate target without altering the reserves supply become pivotal in capturing the causal impact of the government debt supply on the liquidity premium. The implementation of monetary policy through a floor system provides such an opportunity. By supplying abundant reserves to the extent that banks' demand for liquidity no longer responds to the quantity of reserves, the interbank rate aligns with the interest paid on central bank reserves (IOR). In this scenario, reserves and the IOR become two independent tools, enabling a regression analysis of the liquidity premium on the supply of T-bills to unveil the causal impact of the debt supply. Including the IOR in the regression estimates isolates the effect of the monetary policy rate from the influence of the reserves' supply.

Although the U.S. Federal Reserve has conducted something close to a floor system since late 2008 (when it increased the reserve supply and started paying interest on them), the Quantitative Easing (QE) programs deployed in 2009-2014 endogenously altered the supply of reserves, and the IOR remained unchanged until December 2015. For this reason, the empirical exercise is implemented using data from New Zealand, which transitioned to a floor system in 2006 and did not reach the zero lower bound or deploy QE until March 2020. The analysis reveals that an increased supply of debt significantly diminishes the liquidity premium, validating the role of government borrowing. Surprisingly, the level of the IOR also substantially reduces the liquidity premium. This finding contrasts with Nagel's (2016) positive effect of the interbank rate. Under a corridor system with no interest paid on reserves, the interbank rate represents the opportunity cost faced by banks in holding reserves. A higher interbank rate elevates the opportunity cost of reserves, consequently raising the liquidity premium of substitutes such as government debt. However, under a floor system where the IOR equals the interbank rate, this opportunity cost is zero, and one would not expect it to impact the liquidity premium of government debt.

To explain these results, I propose a model and discuss its implications for fiscal capacity and monetary policy transmission. Inside money issued by banks (deposits) earns a convenience yield for its liquidity for households. Banks can issue deposits, but they encounter two frictions: liquidity shocks, which can only be managed by holding reserves, and leverage constraints: to back inside money, banks can invest in high-quality assets (central bank reserves or short-term government bonds). Thus, short-term government bonds earn a convenience yield measured by the spread between the interest rate on household savings and the interest rate on government bonds held by banks.

In a floor system, the central bank supplies abundant reserves, rendering them irrelevant for managing liquidity frictions. The interbank rate falls to equal the IOR, disentangling the supply of reserves from the interest paid on them. Consequently, the central bank only needs to set the IOR to fulfill its inflation mandate. This has three noteworthy consequences: first, from the bank's perspective, the only difference between reserves and T-bills lies in collateral quality. Second, the central bank does not control the short rate of the nominal pricing kernel due to the existence of a convenience yield. Third, notice that although the reserve supply does not need to be closely monitored to achieve the policy rate target, the supply still matters as it affects the supply of collateral available to banks.

The model is then employed to illustrate how monetary and fiscal policy interact in determining the liquidity premium of government debt. Three novel results emerge: first, increasing government debt issuance reduces the liquidity premium regardless of its substitutability with other liquid assets; second, monetary policy shocks under a floor system negatively impact the fiscal capacity of the government through their adverse effect on the liquidity premium; and third, under a floor system, the cyclical dynamics of the convenience yield dampen the transmission from the IOR to the intertemporal rate, impairing monetary policy transmission. These findings bear implications for all central banks expected to maintain large balance sheets in the future.

Literature review. The determination of convenience yields is relevant for fiscal and monetary policy. Convenience yields lower short-term equilibrium interest rates (Del Negro et al., 2019; Lenel, Piazzesi, and Schneider, 2019), are at the center of unconventional monetary policy transmission in Krishnamurthy and Vissing-Jorgensen (2011) and Del Negro et al. (2017), and expand the government's fiscal capacity (Mian, Sufi, and Straub, 2021; Reis, 2021; Jiang et al., 2022).

This paper contributes to the empirical literature on convenience yields by untangling the roles of the supply of government debt and monetary policy. Building upon the work of Nagel (2016) and d'Avernas and Vandeweyer (2023), I extend the analysis by exploring the impact of interest rates and the supply of reserves under a floor system. Additionally, I demonstrate that, under an abundant-reserves system, the supply of T-bills negatively affects the liquidity premium irrespective of the substitutability between debt and deposits. The broader implications of supply and demand effects in the Treasury market are central to recent papers, such as Greenwood and Vayanos (2010, 2014), Krishnamurthy and Vissing-Jorgensen (2011), Hanson and Stein (2015), and Vayanos and Vila (2021).

The model presented in this paper extends a framework common to other studies where banks derive a convenience yield from holding bonds. While Lenel, Piazzesi, and Schneider (2019) argue that bonds alleviate banks' balance sheet costs, I simplify this aspect by assuming a reduced-form collateral constraint for the sake of clarity. The modeling of the floor system in this paper aligns closely with Piazzesi, Rogers, and Schneider (2021). These papers share the feature of the central bank not controlling the short rate of the nominal pricing kernel due to the existence of a convenience yield, unlike Nagel (2016) and Drechsler, Savov, and Schnabl (2017). However, they exclude a government and do not explore the interactions between fiscal and monetary policy. While there are related studies analyzing the convenience yield of bank deposits and their role in monetary policy transmission (Dreschler, Savov, and Schnabl, 2017, 2018), I streamline the dynamics of liquid deposits to maintain focus on the convenience yield of government debt, abstaining from modeling well-known market structure issues in the banking sector.

Floor systems have been extensively studied in New Keynesian models, primarily focusing on optimal policy and their impact on real activity (Curdia and Woodford, 2011; Canzoneri, Cumby, and Diba, 2017; Arce et al., 2020; Piazzesi, Rogers, and Schneider, 2021;

Benigno and Benigno, 2021). In contrast, this paper aims to describe the interaction between the monetary and fiscal authorities and their collective impact on fiscal sustainability and monetary policy transmission.

The structure of the paper unfolds as follows: Section 2 elucidates the empirical strategy and its results, while Section 3 presents a model to expound upon those findings. Section 4 delves into how monetary and fiscal policy interact in determining the liquidity premium of government debt, and Section 5 provides the concluding remarks.

2 Empirical analysis

Consider the following regression of the determinants of the liquidity premium. Nagel (2016) derives it from a formal model and estimates it through instrumental variables:

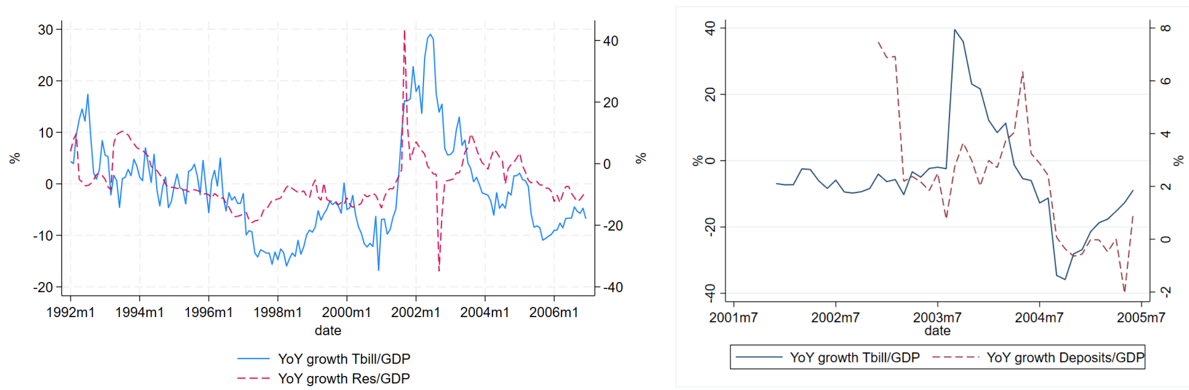
$$LP_t = \beta_0 + \beta_1 FFR_t + \beta_2 (Tbills/GDP)_t + \epsilon_t \tag{1}$$

where LP_t is the liquidity premium of T-bills, FFR_t is the level of the interbank rate set by the central bank under a corridor system (the federal funds rate in the case of the United States), and $(Tbills/GDP)_t$ is the total supply of T-bills. Nagel (2016) estimates this regression for the United States with data from 1991 to 2011, when the U.S. Fed mostly used a corridor system of monetary policy (until late 2008). His results show that $\hat{\beta}_1 > 0$ and $\hat{\beta}_2 = 0$. This leads Nagel (2016) to conclude that the supply of T-bills does not affect their liquidity premium, which would only depend on the level of monetary policy rate set by the central bank. The explanation would go as follows: under scarce reserves, the level of the federal funds rate is linked one-to-one with the supply of reserves, which in turn determines the cost of issuing deposits by banks. Deposits and T-bills must be very close substitutes in providing liquidity services. Therefore, by elastically supplying new reserves, the central bank can fully control the price of both assets. For example, if the government suddenly supplies fewer T-bills, the central bank can step in by supplying more reserves, and private banks increase their supply of deposits. This implies a central bank continually offsetting new issuance of T-bills by an opposite change in the supply of deposits. Ultimately, the central bank defines the liquidity premium on all liquid assets (deposits and closer substitutes like T-bills), and the composition between the two is irrelevant.

However, data for periods when central banks implemented a corridor system shows that T-bills and deposits have a positive correlation along the business cycle. In Figure 1a, I show the correlation between T-bills supply and reserves supply for the United States between 1992

Figure 1: Correlation between T-bills and reserves (scarce-reserve system)

(a) United States: Jan. 1992 - Dec. 2006 (b) New Zealand: Dec. 2001 - Jun. 2005



and 2006. The correlation between the yearly growth rates of T-bills and Deposits is 0.46, significant at the 1% level. The spike in Panel 1a corresponds to September 2001. This result is robust to using deposits-to-GDP instead of reserves. It is difficult to come up with an equivalent Figure for New Zealand, as during this period banks relied mostly on intra-day repos rather than on central bank reserves (more on this later). However, Panel 1b shows that a similar positive correlation arises between T-bills and private checkable deposits, which is an alternative liquid asset (0.44, significant at the 1.4% level, from December 2001 to June 2005, before the floor system)[1].

Since the federal funds rate under a corridor system is closely linked to the supply of reserves, the strong positive correlation between the supply of reserves and T-bills in Figure 1 implies that the regression in (1) suffers from multicollinearity. Therefore, to unveil the causal impact of T-bills on their liquidity premium, one needs to look at instances where the central bank does not alter the supply of reserves to achieve its target.

What explains the positive correlation in Figure 1? The reason might be that the central bank does not respond to T-bill supply, but rather that both the Treasury and the central bank respond to households' demand for liquidity. There could be macroeconomic shocks or long-term stochastic trends. It is challenging to disentangle a precise explanation, and I don't attempt to do it here. The point of Figure 1 is only to show the collinearity between the two series.

I claim that a floor system offers the opportunity to analyze the liquidity premium in

[1]This positive collinearity is consistent with the result in Krishnamurthy and Vissing-Jorgensen (2015), who found that Treasury issuance crowds out less liquid private deposits such as savings and time deposits, but do not crowd-out the most liquid deposits, such as checkable deposits.

instances where the central bank does not need to alter the supply of reserves to achieve its target. Under a floor system, the central bank issues abundant reserves beyond the point where reserve demand by banks becomes flat (and does not respond to supply). This can be understood through the banks' reserve demand model in Poole (1968) or Afonso et al. (2020). In these models, banks demand reserves only to meet reserve requirements, and there are no frictions in the interbank market. Demand is flat at high levels of aggregate reserves, with banks indifferent among a wide range of reserve holdings as long as market rates (including the interbank rate) equal the interest rate paid on reserves. Since, in this case, central banks operate on the flat part of the banks' demand for reserves, they, in practice, have two independent instruments: the policy rate (the interest on reserves) and the supply of reserves. The former is used to meet its mandate on inflation, and the latter ceases to be closely monitored. Notably, the supply of reserves is no longer endogenous to the conduct of monetary policy and clears up the collinearity with debt supply.

The U.S. Federal Reserve has managed something very close to a floor system since October 2008, when it expanded the supply of reserves and started paying interest on them. However, for most of the time since then, this policy coincided with the conduct of QE (where reserve supply becomes endogenous) and didn't alter the IOR for seven years. Therefore, I study the liquidity premium with data from New Zealand. In July 2006, the Reserve Bank of New Zealand (RBNZ) began transitioning from a symmetric channel system to a floor system (see the Appendix for a detailed description of this transition and its main elements). The level of reserves went from NZ$20 million to around NZ$8 billion in a few months. This level was kept steady until March 2020. At the same time, the interest on reserves (called the Official Cash Rate) was set equal to the interbank rate. Notably, New Zealand did not reach the zero lower bound nor conducted QE until the Covid crisis in March 2020 (when the reserves supply was raised to almost NZ$30 billion), which makes it an ideal scenario to study a floor system.

Data for New Zealand supports the assumption that reserve supply is no longer endogenous to monetary policy under a floor system. The correlation between the interest on reserves and the supply of reserves is not significantly different from zero (for comparison, under a scarce-reserve system, the correlation between the federal funds rate and the supply of reserves is very negative). At the same time, in New Zealand, the correlation between T-bills and reserves is also not significantly different from zero, showing the disconnection between the two under a floor system. The Appendix shows these correlations graphically. It also addresses two specific episodes in which the RBNZ injected liquidity into the banking system, most likely driven by liquidity concerns and, therefore, endogenous.

I estimate the following regression via instrumental variables:

$$LP_t = \alpha_0 + \alpha_1 i_t^m + \alpha_2 (Tbill/GDP)_t + v_t \tag{2}$$

In this equation, coefficients will have a different interpretation as in (1). α_1 captures the effect of the level of interest rates stripped from its effect through the supply of reserves. A monetary policy tightening (an increase in the IOR) no longer involves a decrease in the supply of reserves. What is the expected sign of $\widehat{\alpha}_1$? If the central bank pays a higher yield on its reserves, banks will ask for a higher yield on T-bills to be willing to hold them. A higher yield on T-bills will be accommodated via a lower liquidity premium. Therefore, we should expect $\widehat{\alpha}_1 < 0$. The coefficient $\widehat{\alpha}_2$ will capture the causal effect of the supply of T-bills, no longer confounded by the collinearity with the supply of reserves.

2.1 Data

I follow the literature's convention and measure the liquidity premium of T-bills by taking their spread against other assets of similar maturity and credit risk. The intuition is that since the maturity and credit risk are the same, the remaining spread must be due only to their liquidity services. The spread, then, is a measure of the extra price investors are willing to pay for the liquidity of the T-bills. For New Zealand data, I use two assets comparable to T-bills: 3-month bank bills and 6-month term deposits.

Bank bills are a common investment in Australia and New Zealand: it is a promise by the borrower to pay the face value at maturity. It is considered a safe investment because they are "accepted" (guaranteed) by a bank. In accepting the bank bill, the bank makes the payment at maturity, regardless of the borrower's repayment ability. Investors can buy bank bills from a bank for an agreed face value, an agreed term, and a quoted interest rate. The bank then endorses the bank bills to acknowledge the change in ownership. Upon maturity, the bank will pay the full face value, which includes the initial purchase price and the interest receivable. An additional feature of investing in bank bills is that should you require funds before the due date, the bank will purchase the bank bill at the prevailing interest rate. Although this last feature might make them as liquid as a T-bill, they have consistently traded at yields above T-bills, with the spread spiking during the turmoil of 2008.

On the other hand, the spread between term deposit rates and T-bill rates is one of the measures used in Krishnamurthy and Vissing-Jorgensen (2012) for U.S. data. Like the U.S., term deposits in New Zealand are a safe investment where investors lock in a competitive interest rate for a fixed term. Investors are usually not allowed to redeem their money before the term's expiration. Some banks allow it in specific circumstances and require early notifications. Therefore, the spread should account for the liquidity provided by the T-bill.

The liquidity premium measured with these two assets is sizable. The bank bill has a yield of 28 basis points above T-bills on average for January 1996-July 2021. The term deposit has a larger spread of 63 basis points on average. The larger spread for the term deposit might come from two sources. First, its maturity is six months rather than three. Second, this might be due to the higher liquidity of the bank bill, which makes it more similar to the T-bill. Recall that the bank bill can be sold any time during the instrument's term, while the investment in the term deposit is locked in for the whole period. Standard deviations are high: 24 and 80 basis points, respectively.

2.2 Results

I estimate Equation (2) via instrumental variables. The dependent variable is the spread between the 6-month term deposit and the 6-month T-bill. Data starts in March 2009 (the month the New Zealand Treasury started auctioning 6-month instruments). The independent variables are the interest on reserves, the VIX index -to account for demand shifts due to uncertainty-, the supply of government debt (which I proxy by using the supply of T-bills or the supply of debt of all maturities), and the supply of deposits or reserves. The latter accounts for the few instances where the RBNZ injected reserves for endogenous reasons. I use two measures of the supply of deposits: the total amount taken from the banking system's balance sheet and the total amount taken from the households' balance sheets. Newey-West standard errors correct for autocorrelation.

For robustness, I run the regressions in the Appendix using the spread between the 90-day Bank Bill and the 3-month T-bill to measure the liquidity premium. It also shows robustness to estimating the regression in first-differences and to dropping the Covid pandemic months.

Instrumental variables for the monetary policy rate are essential since an unobserved liquidity demand shock (correlated with interest rates or the supply variables) may induce the central bank to lower interest rates in the same month, leading to reverse causality. This would result in a downwardly biased estimate of the interest rate coefficient.

To instrument the interest rate, I follow Piazzesi and Swanson (2008) and use their risk-adjusted forecast from future contracts. Futures contracts settle at the end of each month based on the average rate that prevails during that month. The futures price in months prior to the expiration month should be highly correlated with the average federal

Table 1: Determinants of the liquidity premium - 2SLS

	(1)	(2)	(3)	(4)
ior_t	-0.323***	-0.387***	-0.214**	-0.217***
	(0.1213)	(0.111)	(0.122)	(0.055)
$\log(\frac{Tbill}{GDP})_t$	-0.446***	-0.405***		
	(0.162)	(0.154)		
$\log(\frac{Debt}{GDP})_t$			-0.653*	-0.498*
			(0.340)	(0.276)
$\log(\frac{HHDeps}{GDP})_t$	-4.628***			
	(1.058)			
$\log(\frac{Deps}{GDP})_t$		-5.881***	-1.386	
		(1.259)	(1.559)	
$\log(\frac{Reserves}{GDP})_t$				-0.953***
				(0.190)
vix_t	-0.00106	-0.00108	-0.0098	0.0164
	(0.0118)	(0.0128)	(0.0106)	(0.0117)
Constant	4.348***	8.779***	3.7411	-0.459
	(0.996)	(1.741)	(2.377)	(0.525)
Instruments for:				
IOR	Y	Y	Y	Y
Tbill/Debt supply	Y	Y	Y	Y
Deposits/Reserves	Y	Y	Y	Y
Weak instruments test				
CD stat	22.1	26	22.88	40.35
SY critical value	8.5	8.5	8.5	8.5
Observations	149	149	149	149
R-squared	0.254	0.287	0.2711	0.357

Notes: Data are at monthly frequency. Units are hundredths of basis points. The dependent variable is the 6-month Term deposit/Tbill spread. $\log(\frac{Debt}{GDP})_t$ includes outstanding government debt of all maturities. $\log(\frac{HHDeps}{GDP})_t$ are total deposits in households' balance sheet. $\log(\frac{HHDeps}{GDP})_t$ are deposits in the monetary base. Instruments for debt supply are nonlinear functions of the total debt-to-GDP ratio. Instruments for the supply of deposits are nonlinear functions of the ratio of T-bills to GDP. A CD stat greater than the Stock and Yogo critical value rejects weak instruments (with bias greater than 10% of OLS bias). Newey-West standard errors in parenthesis (3 lags).

funds rate during the expiration month. However, Piazzesi and Swanson (2008) show that futures prices include a non-negligible risk premium that can be correlated with the liquidity premium. For this reason, I use the price of the 1-month ahead future contract from two months prior to the expiration month to avoid a correlation between the instrument and the dependent variable.

I use nonlinear functions of the total debt to GDP ratio to instrument the supply variable. Nonlinear functions of total debt to GDP exploit the positive correlation between total debt and its maturity structure. For example, this instrument has been used by Krishnamurthy and Vissing-Jorgensen (2012).

Table 1 shows the results. Columns 1 and 2 use the supply of T-bills as a measure of the supply of government debt. The coefficient on T-bill supply is negative and significant. A one percent increase in the supply of T-bills reduces the liquidity premium by 41 and 46 basis points. This result is robust to the measure of the supply of deposits used. The magnitude is lower than in Krishnamurthy and Vissing-Jorgensen (2012) but is much larger than the non-significant effect found by Nagel (2016) for the U.S. data.

Interestingly, the coefficient of the interest on reserves is significantly negative. This is the effect of the monetary policy rate stripped from its connection with the supply of central bank reserves. It represents the effect of tightening monetary policy under an ample reserve system. This is a complete switch of the sign in the impact of the monetary policy rate on the liquidity premium estimated in Nagel (2016) under a scarce-reserves system. The Appendix shows that this negative coefficient also shows up for data in the U.S. after 2008, even though, in that case, the caveat of an endogenous supply of reserves still applies.

Columns 3 and 4 replicate the first two columns but include the supply of debt of all maturities as a proxy for the supply of government debt. Both the coefficient on the IOR and the negative effect of government debt are robust. A one percent increase in the supply of total debt reduces the liquidity premium by between 50 and 65 basis points.

Notably, the instruments in Table 1 are strong, as shown by the relatively high Cragg-Donald statistics. A statistic greater than the critical values from Stock and Yogo (2005) -also shown- rejects the hypothesis of weak instruments (with bias greater than 10% of the OLS bias) at a significance level of 5%.

3 Model

In this section, I set up a model to explain the empirical results and characterize fiscal and monetary policy implications. This is an endowment economy-representative agent model comprised of households, who derive transaction services from inside money (bank deposits); banks, who provide deposits by accumulating central bank reserves and other assets; a fiscal authority who sets the supply of T-bills; and a central bank that conducts monetary policy. The model is set with flexible prices, but most implications would also hold in a version with endogenous income and sticky prices.

In the model, the liquidity premium on government bonds arises at the bank level because bonds are good collateral for issuing deposits. The liquidity premium will equal the spread between the rate of household savings governing intertemporal decisions and the rate on government bonds. In most of the recent papers on liquidity premia, government bonds are held by banks, and they earn a convenience yield because of micro-founded balance sheet costs (Lenel, Piazzesi, and Schneider, 2019; Vandeweyer, 2021).

3.1 Households

There is a single perishable consumption good with endowment stream $\{Y_t\}$. The endowment follows an exogenous process:

$$\log Y_{t+1} = \rho_y \log Y_t + \epsilon_{t+1} \quad , \epsilon_t \sim N(0, \sigma^2) \tag{3}$$

The representative household seeks to maximize the objective:

$$\mathbb{E}_0 \sum_{t=1}^{\infty} \beta^t [u(C_t) + \alpha \log(D_t/P_t)] \tag{4}$$

where C_t is consumption, and liquidity services are supplied by money in the form of deposits. D_t/P_t denotes real balances of deposits. These liquidity benefits arise from some unmodeled use in intra-period transactions. P_t is the nominal price of the consumption good. A model period is one quarter, and deposits and T-bills have a one-period maturity.

Households optimize subject to the flow budget constraint:

$$\begin{aligned} D_t + k_t A_t - L_t + P_t C_t &= D_{t-1}(1 + i^d_{t-1}) \\ &+ k_{t-1}(A_t + P_t Y_t) - T_t - L_{t-1}(1 + i_{t-1}) + \Omega_t \end{aligned} \tag{5}$$

where k_t denotes the share of total endowment stream that the household owns at the end of period t, A_t is the price of the claim to the endowment stream, T_t denotes transfers/taxes from the government, i^d_t is the interest rate on deposits, L_t denotes loans, Ω_t is the flow of profits from banks to households, and i_t is the nominal interest rate applicable to assets and transactions that do not produce a liquidity service flow.

The household first-order condition for consumption yields the intertemporal Euler equation

$$1 = \beta \mathbb{E}_t \left[\frac{u_c(C_{t+1})}{u_c(C_t)} \frac{1 + i_t}{\Pi_{t+1}} \right] \tag{6}$$

where u_c denotes the first derivative of $u(.)$ and $\Pi_{t+1} = P_{t+1}/P_t$. The illiquid rate i_t in Equation (6) governs the household's intertemporal decisions; thus, this is the rate the monetary authority looks to affect. However, as explained below, the central bank's policy rate is the rate on deposits, i^d_t, which will carry a convenience yield and trade below the i_t.

The first-order condition with respect to real deposit balances is:

$$\frac{\alpha}{\frac{D_t}{P_t}} = u_c(C_t)\frac{i_t - i_t^d}{1 + i_t} \tag{7}$$

Equation (7) reflects households' valuation of inside money or deposits. Since households derive transaction services from deposits, they are willing to accept an interest rate on deposits i_t^d below the intertemporal rate. The households' cost of liquidity, $i_t - i_t^d$, reflects the value of money for making payments. It is declining in real balances: the marginal benefit of payment instruments is declining in the overall quantity held.

3.2 Banks

The representative bank in this economy exists because households cannot access the central bank's reserves directly. The bank, therefore, issues liquid deposits, on which they promise to pay a riskless nominal return i_t^d one period later, by either holding reserves at the central bank, M_t^d, that receive a nominal yield of i_t^m or having other assets such as loans, L_t^s, or T-bills, B_t^h, on which they earn a nominal interest rate of i_t and i_t^b, respectively. The bank takes all these interest rates as given. In what follows, lower-case variables denote real variables.

In most models of banking, reserves play a unique role in liquidity management: from a representative bank facing real intermediation and liquidity costs (Lenel, Piazzesi, and Schneider, 2019; Curdia and Woodford, 2011) to a mass of banks facing idiosyncratic liquidity needs (Arce et al., 2020; Piazzesi, Rogers, and Schneider, 2021). When reserves are scarce, as in a corridor system, banks are willing to forgo a return (the spread between the interbank rate and the interest paid on reserves) to hold them, and the central bank targets an interbank rate by altering the supply of reserves.

In the current setting, to resemble a floor system, I follow Piazzesi, Rogers, and Schneider (2021) and assume that because reserves are abundant, they play no special role in managing liquidity costs. However, reserves play an additional role as high-quality collateral because banks face a leverage constraint: to back deposits, banks need to invest in central bank reserves or T-bills. From the perspective of the bank, the only difference between reserves and other assets is collateral quality.

It must be emphasized that while reserves play no special role in liquidity management, the households' demand for liquidity remains positive because of Equation (4), which assumes no satiation in deposit holdings.

Banks' nominal cash flows at date t are given by:

$$M_{t-1}(1+i^m_{t-1}) - M_t + B^h_{t-1}(1+i^b_{t-1}) - B^h_t + L_{t-1}(1+i_{t-1}) - L_t - D_{t-1}(1+i^d_{t-1}) + D_t \quad (8)$$

Banks maximize the present value of this cash flow, discounted at the illiquid rate, i_t, which represents the household discount factor and hence the banks' cost of capital.

Banks can issue deposits only if they have sufficient collateral to back them:

$$D_t \leq M_t + \rho_b B^h_t \quad (9)$$

where $\rho_b < 1$ captures the idea that reserves are better collateral than other assets. A leverage constraint can be viewed as a simple way to model an increasing marginal cost of debt. Models such as the one in Lenel, Piazzesi, and Schneider (2019) achieve this through more micro-founded balance sheet costs.

Deposits represent a cheaper source of funding than equity because of the non-pecuniary services deposits provide to households. Without a leverage constraint, it would be optimal to fund the bank entirely with deposits. Therefore, the leverage constraint will always bind in equilibrium.

The first-order conditions for reserves, T-bills, and deposits are, respectively

$$\frac{i_t - i^m_t}{1+i_t} = \gamma_t \quad (10)$$

$$\frac{i_t - i^b_t}{1+i_t} = \rho_b \gamma_t \quad (11)$$

$$\frac{i_t - i^d_t}{1+i_t} = \gamma_t \quad (12)$$

where γ_t is the Lagrange multiplier on the leverage constraint. A binding leverage constraint induces a spread between the illiquid rate and the rate on T-bills, which corresponds to the convenience yield on T-bills. It indicates that banks value T-bills not only for their interest rate, but also for their collateral value that allows them to issue more cheap deposits.

The Appendix shows how one could analyze a corridor system by including costs arising from liquidity management.

3.3 Government and Central Bank

The government is comprised of a fiscal authority and a central bank. The fiscal authority's flow budget constraint is given by:

$$B_t^s = (1 + i_{t-1}^b) B_{t-1}^s + G_t - T_t - T_t^{cb} \tag{13}$$

where B_t^s is total debt issued, G_t is fiscal spending, T_t are tax/transfers to the household, and T_t^{cb} are transfers from the central bank.

The central bank buys government bonds and pays with the issuance of new reserves to the banking system. Its budget constraint is:

$$M_t^s + (1 + i_{t-1}^b) B_{t-1}^{cb} = B_t^{cb} + M_{t-1}^s (1 + i_{t-1}^m) - T_t^{cb} \tag{14}$$

where M_t^s is the supply of reserves and B_t^{cb} are its holdings of government bonds. Notice that $B_t^s = B_t^h + B_t^{cb}$, and therefore the budget constraint for the consolidated public sector is:

$$B_t^h + M_t^s = (1 + i_{t-1}^b) B_{t-1}^h + M_{t-1}^s (1 + i_{t-1}^m) + G_t - T_t \tag{15}$$

Letting $U_t = B_t^h + M_t^s$, the consolidated budget constraint becomes $U_t = U_{t-1} + Z_t$, where $Z_t = i_{t-1}^b B_{t-1}^h + M_{t-1}^s i_{t-1}^m + G_t - T_t$ is the total deficit, inclusive of interest payments.

In real terms, the budget constraint becomes:

$$u_t = \frac{u_{t-1}}{\Pi_t} + z_t \tag{16}$$

where lower case letters denote real variables and $\Pi_t = P_t / P_{t-1}$. I assume that fiscal policy is governed by a rule for setting the real deficit:

$$z_t = z e^{\zeta_t} - \rho_g u_{t-1} \tag{17}$$

where ζ_t will is an exogenous deficit shock and z a parameter to be calibrated. The parameter ρ_g captures the response of the current deficit to the outstanding debt. A positive value resembles a government that follows a sustainable path, as Bohn (1998) describes. For simplicity, I assume $G_t = 0$. In this model, bonds' transaction services will affect equilibrium inflation. Therefore, the fiscal and monetary policy will interact in a way absent in standard models where bonds do not provide transaction services. Canzoneri and Diba (2005) show that, in this framework, the government needs to set fiscal policy in real terms to achieve local determinacy in the inflation rate.

3.4 Monetary policy implementation

The monetary authority conducts monetary policy to meet an interest rate operating target, i_t^{m*}, for the IOR, according to the policy rule

$$i_t^{m*} = \psi \Pi_t^{\psi_\pi} e^{\xi_t} \tag{18}$$

where ξ_t is an exogenous monetary policy shock. Equation (18) rules out the possibility of a zero lower bound, as the calibration for New Zealand in the period before 2020 will not involve such episodes.

In addition, the central bank sets a path for the quantity of reserves. I assume the central bank keeps reserves abundant, and banks do not face liquidity costs. Notice that although their supply is disentangled from the policy rate, their supply still matters as it affects the supply of collateral available to banks.

This represents how the Fed has conducted monetary policy since 2008. The interest rate on reserves and the federal funds rate are the tools used to reach its goals of inflation and unemployment, and the supply of reserves is not followed closely[2]. Indeed, the Fed's January 2019 statement reads: "*The Committee intends to* ***continue*** *to implement monetary policy* ***in a regime in which an abundant supply of reserves*** *ensures that control over the level of the federal funds rate and other short-term interest rates is exercised primarily through the setting of the Federal Reserve's administered rates, and in which* ***active management of the supply of reserves is not required***" (emphasis is mine).

How does this setting differ from a corridor system? In a corridor system, reserves are scarce, and they are valued as a way to handle liquidity shocks in addition to leverage constraints. Reserves are more useful for handling liquidity shocks than other assets: banks can get them by borrowing from other banks at a premium, measured as the spread between the interbank rate and the IOR. The central bank thus targets a positive spread between the interbank rate and the IOR, and elastically supplies reserves to achieve that spread. Since the central bank effectively targets two interest rates, the quantity of reserves is not an independent policy instrument. If the central bank lowers the supply of reserves but keeps the same IOR, the interbank rate will rise above the target.

Notice that the convenience yield drives a wedge between the rate that the central bank controls, i_t^m, and the rate that the central bank wants to affect, the intertemporal interest rate governing consumption/savings decisions, i_t. Therefore, the transmission from the policy

[2] Except for the period starting in the second half of 2022, when, due to the inflation surge, the Fed decided to run down the size of the balance sheet.

rate to the intertemporal rate will depend on the endogenous response of convenience yields. This will be explored in more detail in the next Section.

Definition: An equilibrium in this economy are prices $\{i_t, i_t^b, i_t^m, A_t, \Pi_t\}$ and policy rules $\{C_t, d_t, l_t, b_t^h, d_t^s, b_t^s, l_t^s\}$ such that:

1. Given prices, households maximize lifetime utility, banks maximize future cash flows,
2. All markets clear: $k_t = 1$, $D_t = D_t^s$, $L_t = L_t^s$, $B_t^h = B_t^s$.

I solve the model using the toolbox developed by Cao, Luo, and Nie (2023). The remainder of the paper has a predominantly qualitative goal: to show how fiscal and monetary policy interact in determining the liquidity value of government debt. The model is too simple to give a complete quantitative characterization of the New Zealand economy. However, to ensure that the analysis comes from reasonable values of the parameters, I calibrate the model to match the debt and reserves levels and the liquidity premium of New Zealand's assets (see Appendix).

4 Monetary and fiscal policy interactions

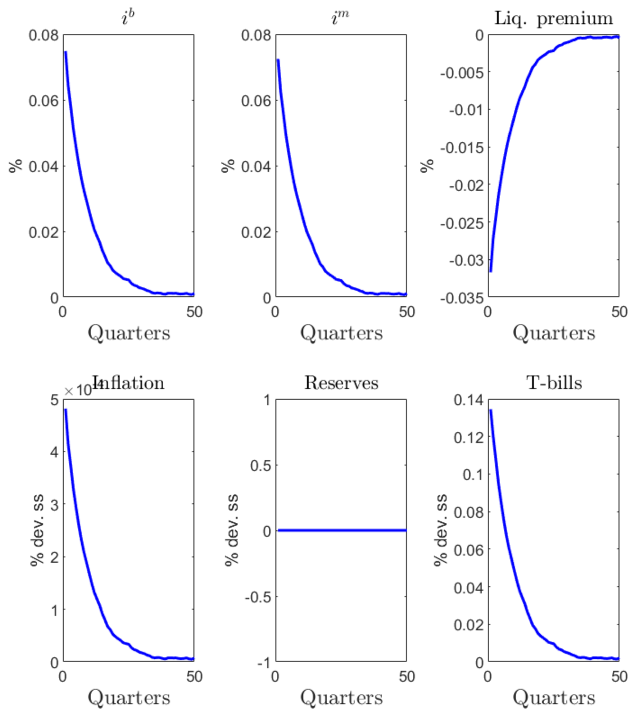
4.1 Shock to the supply of debt

First, I consider an exogenous increase in the deficit financed by the rise in the supply of government debt. In New Zealand data, the annual growth rate of the supply of T-bills between January 2008 and February 2020 has a mean of 6.25% and a standard deviation of 79. The debt issuance in response to the global financial crisis influences this sizeable standard deviation. I consider an increase in ζ_t of 1% over a year. The blue line in Figure 2 compares the impulse responses of the yield on T-bills, the liquidity premium, inflation, and central bank reserves for the calibration described in the Appendix.

The exogenous increase in the deficit is financed by an increase in government borrowing, which directly affects the liquidity premium as the marginal convenience yields of liquid assets decrease. In addition, it increases the availability of collateral for banks and, therefore, the supply of deposits. The latter is inflationary, which calls for an increase in i_t^m via the central bank's rule. Notice that the rise in i_t^m does not imply a decrease in the supply of reserves, which is the main feature of the floor system. Intuitively, from a liquidity preference perspective, the yields on liquid assets have to rise so as to encourage banks to hold the new supply of them, and a reduction in the convenience yield accommodates this.

Under a corridor system, the central bank would also raise the interest rate (the interbank rate in this case), but this would need a reduction in reserves and, as banks face higher

Figure 2: Positive debt supply shock - Floor system



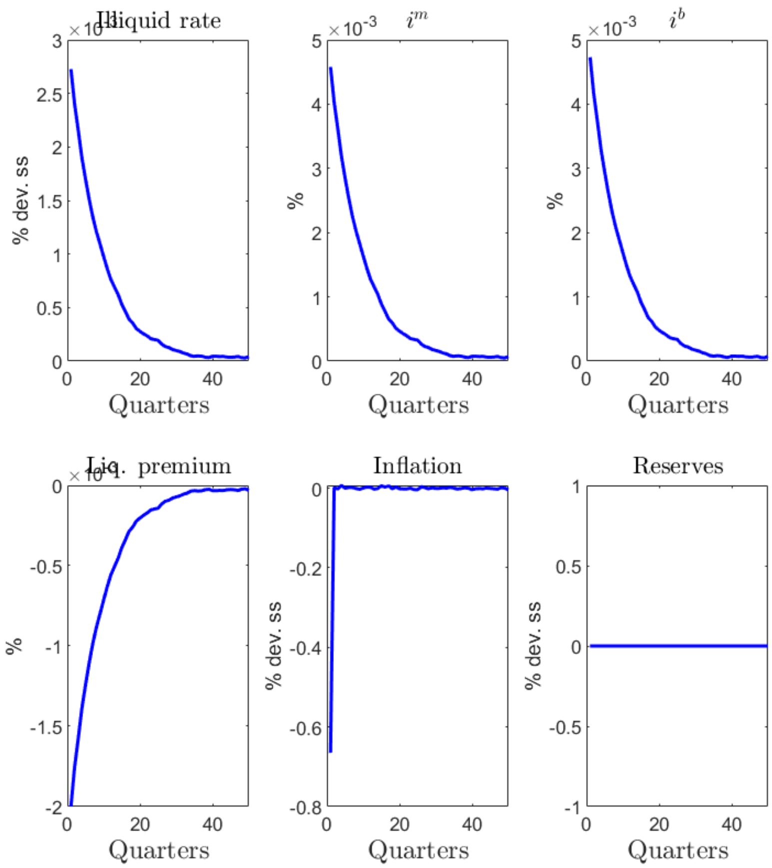
liquidity costs, would result in a more significant drop in the supply of deposits. This drop in the supply of reserves and deposits would offset the increase in debt supply; if they are perfect substitutes, then there would be no change in overall liquidity supply and no change in the liquidity premium. This is how Nagel (2016) explains that the debt supply has no statistical significance in his regressions.

One implication from Figure 2 is that, under a floor system, the debt supply has an impact on the liquidity premium even when reserves and bonds are perfect substitutes. d'Avernas and Vandeweyer (2023) extend the regressions in Nagel (2016) and find that the debt supply has become statistically significant in the United States after 2008. Starting from Nagel (2016) this leads them to conclude that it must be because deposits and T-bills are no longer perfect substitutes. Figure 2 shows that such a result might not be conclusive about the degree of substitutability between T-bills and other forms of liquidity.

4.2 Monetary Policy Shock

In this subsection, I consider a positive realization of ξ_t in the Taylor rule (18). The monetary policy shock in the model is assumed to follow an iid process. The 25 basis point shock

Figure 3: Monetary Policy Tightening - Floor System



increases the interest paid on reserves, with everything else equal, by 1% at annual rates. In Figure 3, I set the parameter ρ_b at 0.8, reflecting high substitutability.

The distinctive feature of the monetary policy shock under a floor system is that it involves a rise in the IOR without a change in the supply of collateral (reserves). Banks are now being paid more for the high-quality collateral they hold. Therefore, their cost of collateral drops. In this model, banks pass through this lower cost by raising the interest they pay on deposits, which lowers the households' cost of liquidity.

The lower households' cost of liquidity translates into a lower liquidity premium on government debt. Why? In the current model of exogenous endowment and flexible prices, the positive realization of ξ_t lowers current inflation. The lower inflation increases the real supply of government debt, and, therefore, it reduces the marginal value of liquidity services. The lower marginal value of liquidity services lowers the willingness to pay for the liquidity provided by T-bills, as shown in Figure 3. Alternatively, in a model with endogenous income and sticky prices, the shock would increase i_t^m with little effect on the price level and the real value of government debt. However, it would reduce the demand for consumption and, therefore, reduce the convenience yield through lower demand for liquidity.

In the Appendix, I validate the model by showing that under a corridor system, it gives a positive correlation between the interbank rate and the liquidity premium (as found in Nagel, 2016) and a positive correlation between the supply of reserves and the supply of T-bills (seen in Section 2). Because of the model's simplicity, I only aim to match the sign of the correlation, not its magnitude.

4.3 Implications for fiscal capacity

Standard fiscal capacity analysis tells that higher interest rates reduce the expected present discounted value of primary surpluses and thus reduce the sustainable debt-to-GDP ratio. However, the model implies the existence of an additional channel: higher interest rates can reduce the fiscal capacity through their negative effect on the liquidity premium.

To see this, take the government's budget constraint in (16), ignoring for now the role of reserves as a liability for the government. Iterate it forward, and impose the transversality condition $\lim_{n\to\infty} E_t[q_{t,t+n}b_{t,t+n}] = 0$ to get:

$$b_t = \mathbb{E}_t\left[\sum_{j=1}^{n} q_{t,t+j}s_{t+j}\right] + \mathbb{E}_t\left[\sum_{j=1}^{n} q_{t,t+j}(i_t - i_t^b)b_t\right] \tag{19}$$

where $q_{t,t+j} = \mathbb{E}[\beta^j(u'(C_{t+j})/u'(C_t))]$ is the model-based stochastic discount factor. The left-hand side in Equation (19) corresponds to the current debt-to-GDP ratio (recall that steady state endowment has been normalized to one). The first term on the right-hand side is the expected discounted present value of future primary surpluses. The second term is the expected discounted present value of future liquidity services.

What Equation (19) shows is that the fiscal capacity of the government increases when government debt provides safety and liquidity services to investors: the current value of debt-to-GDP can be above the present discounted value of primary surpluses thanks to the second term on the right-hand side, which depends on the magnitude of the liquidity premium, $i_t - i_t^b$. This term is what Reis (2021) calls the "debt revenue" term. Fiscal capacity analysis for the U.S. by Mian, Sufi, and Straub (2022) and Jiang et al. (2022) assumes the debt revenue term depends negatively on the debt supply.

Equation (19) can give an idea of the economic magnitude of the convenience yield in New Zealand's data. An average liquidity premium of 1.2% over the period coupled with a mean debt-to-GDP ratio of 0.42 gives a flow debt revenue of 0.5% of GDP. Discounting at the mean illiquid rate of 2.44% (4.44% nominal rate minus 2% inflation) and ignoring risk or uncertainty in calculating the present value over a long time horizon implies that debt revenue can sustain $0.5/0.024 = 20.8\%$ of GDP in public debt. This number is lower than the ones obtained by Reis (2022) for the U.S. and other G7 countries.

A few caveats to this magnitude. First, of course, it assumes that all debt is short-term and, therefore, enjoys the convenience yield of T-bills. A more complete analysis would consider debt at different maturities and consider that longer maturities are less money-like than T-bills. Second, it does not consider central bank reserves as a potential debt obligation for the Treasury.

What is the impact of monetary policy on the fiscal capacity of the government? In the model, a monetary policy shock increases the debt burden of the government in real terms (due to the fall in inflation), which increases borrowing and reduces deficits in the future (per the fiscal rule in (17)). This impact is qualitatively the same regardless of how monetary policy is conducted.

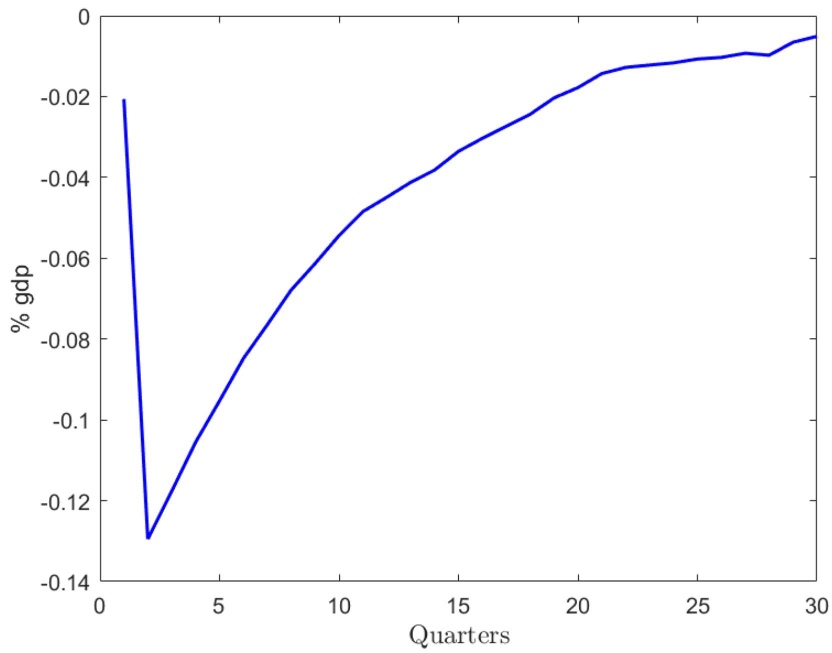
The floor system will have a distinctly negative impact on the "debt revenue" term in (19). Figure 4 below shows the response of the "debt revenue" term to the same monetary policy shock analyzed in Section 4.2. The fiscal capacity of the government drops along with the debt revenue term. There is a sharp decrease during the first two quarters as the drop in inflation raises real rates. After that effect, fiscal capacity recovers only slowly because of the slow dynamics of the liquidity premium.

This result can bring new insights into the sharp tightening cycle on which advanced economy central banks have embarked since early 2022. This tightening coincided with high debt-to-GDP levels due to the fiscal response to the Covid-19 crisis. Although more research is needed, it might be a relevant element in the discussion on the optimal size of the central bank's balance sheet.

4.4 Implications for monetary policy transmission

A feature of the model in Section 3 is that convenience yields drive a wedge between the rate that the central bank controls and the rate that the central bank wants to affect (the intertemporal rate). Therefore, the transmission from the policy rate to the intertemporal rate will depend on the response of convenience yields. Since the corridor and the floor systems manage liquidity differently, they will have different outcomes regarding monetary policy transmission.

Figure 4: Impulse Response Function of Debt Revenue to a Monetary Policy Shock



Proposition 1 *In response to a business cycle shock, under a floor system, the reaction of the convenience yields dampens the transmission of changes from the interest on reserves to the intertemporal rate.*

Proof: see the Appendix.

To see the intuition of this result, consider a good realization of the exogenous endowment process, Y_{t+1}. This increases the demand for consumption and, therefore, the demand for liquid assets. To avoid an increase in the price level, the central bank needs the intertemporal rate, i_t, to increase.

The central bank will accommodate this by an increase in interbank rate (under a corridor system) or the interest on reserves (under a floor system). However, the pass-through of this increase to the intertemporal rate will depend on the response of the households' convenience yield of deposits (Equation (7)). Under a corridor system, the reduction in the supply of reserves needed to raise the interbank rate will translate into fewer deposits (via the binding collateral constraint), increasing the convenience yield of deposits and further pushing the intertemporal rate up.

The interest on reserves under a floor system will require a more significant increase in magnitude. The first reason is that there is no reduction in the supply reserves, so the effect described in the previous paragraph does not apply. Second, the government will actually issue new debt in response to the higher consumption demand, reducing the households' convenience yield and pushing the intertemporal rate in the opposite direction. As a result, i_t^m in a floor system will need to rise by more than the interbank rate in a corridor system[3].

Consequently, under a floor system, a central bank will need to adjust its response function to business cycle shocks compared to a corridor system. A central bank transitioning from a corridor to a floor system and not considering this runs the risk of running inflation persistently above its target.

5 Conclusions

This paper has provided new insights into how monetary and fiscal policy interact in determining the liquidity premium of short-term government debt. Clearing up the collinearity between the supply of T-bills and its close substitutes showed that the supply of government debt negatively impacts its liquidity premium. This result mainly implies that a government that borrows too much can reduce the premium and eventually exhaust it. From the perspective of fiscal policy, too much borrowing can lessen the debt revenue term in the government's budget constraint. This confirms previous assumptions in the literature that a government cannot indefinitely exploit the seignorage revenue coming from the safety/liquidity of its debt.

At the same time, the floor system allows one to estimate the impact of interest rates, stripped of their link to the supply of central bank reserves. The interest on reserves has a negative impact on the liquidity premium, even when central bank reserves have no opportunity cost for banks. This implies that increases in the monetary policy rate under a floor system can have further adverse effects on the government's fiscal capacity. As the number of advanced economies implementing an abundant-reserves system has grown in the past decade, it is even more critical to understand how this new system has changed this and other linkages between monetary and fiscal policy. One fruitful avenue for future research will be to consider the endogenous debt maturity decisions by the budgetary authority, considering that long-term bonds have less liquidity value than T-bills.

[3]The implication that the proportional magnitude of the response of i_t is different in a corridor versus a floor system can also be found in the model of Piazzesi, Rogers, and Schneider (2021).

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Appendix A Data sources

Yields: the interest on reserves, the 3-month bank bill rate, and the 6-month term deposit rate are from the Reserve Bank of New Zealand (RBNZ) statistics. See Wholesale interest rates, table B2 monthly, for the OCR and the bank bill, and Retail interest rates, table B3, for the term deposit rate. The 3- and 6-month yields on T-bills are calculated from auction results published by the Debt Management Office of New Zealand's Treasury. When more than one instrument is offered, I take the weighted average of successful yields.

Supply of T-bills and deposits: the amount of T-bills outstanding is published monthly by the Debt Management Office of New Zealand's Treasury. Series are at market value. The supply of reserves by the central bank is obtained from the RBNZ's balance sheet (see statistics, table R2). The two proxies for the supply of deposits correspond to households' deposits at registered banks, available at the RBNZ's statistics (see Household balance sheet, table C22), and total deposits calculated as broad money minus currency in circulation (from the RBNZ's balance sheet).

All these variables are scaled by GDP, available at FRED (current price Gross Domestic Product in New Zealand, New Zealand dollars, Quarterly). The series was brought to monthly frequency through interpolation.

Other: the VIX index and the U.S. federal funds rate were obtained from FRED (series VIXCLS and EFFR). Data for bank bills' futures contracts prices (the instrumental variable for the IOR) was obtained from Bloomberg, tickers ZB1 and ZB2. Supply for U.S. T-bills (see Figure 1 in the main text) was obtained from TreasuryDirect. U.S. deposit supply in the same Figure corresponds to the sum of checking and savings accounts in Table 4 in H.6 release (see FRED).

Appendix B Monetary policy in New Zealand

This section relies on Keister et al. (2008) and Selgin (2018) to describe New Zealand's transition to a floor system. From 1999 until July 2006, the Reserve Bank of New Zealand (RBNZ) implemented a symmetric corridor system in which the benchmark policy rate, the Official Cash Rate (OCR), was kept 25 basis points above the rate paid on reserves and 25 points below what was charged for overnight loans. Because banks' overnight settlement balances (i.e., reserves) bore an opportunity cost in such a regime, banks held very few such balances, relying instead on intraday credits from the RBNZ to meet their ongoing settlement needs.

Along with its corridor system, the RBNZ implemented a Real Time Gross Settlement (RTGS) system for wholesale payments, in which interbank payments are settled bilaterally and immediately, thereby becoming final and irrevocable as transactions are processed, rather than at the end of the business day only. This allows payments to be made final as soon as they are processed. If a bank faced any real-time liquidity need in the remainder of the day, it would rely on credit from the RBNZ instead of waiting to settle its net balances at the end of each day.

The disadvantage of the RTGS is that it exposes the central bank to credit risk. The RBNZ chose to supply intraday credit through fully secured reverse repo agreements to avoid that risk. However, the Government of New Zealand had been running a fiscal surplus for a few years, and government bonds had become scarce. Since these bonds were the preferred collateral, the scarcity produced broad volatility in the interbank market and often resulted in rates significantly above the target desired to implement monetary policy. The RBNZ had to accept municipal and corporate paper as collateral, which did not eliminate the risk of losses.

The RBNZ reviewed its liquidity management regime in 2005 and announced a new system in early 2006. Recognizing the danger of losses, the RBNZ encouraged banks to rely on overnight settlement balances (reserves) instead of intraday repos to meet their settlement needs. With that end in mind, in July 2006, the RBNZ began its program of "cashing up" the banking system. The first step was to create an additional NZ$7 billion reserves between July and October. Concurrently, it increased the interest paid on those reserves by 25 basis points (made in five-point increments) to encourage banks to hold them. Next, the RBNZ stopped providing intraday repos. In the end, the RBNZ achieved the two critical components of a floor system: the interest rate on reserves was equal to the policy rate, and banks were well supplied, if not satiated, with liquidity.

Figure 5 plots the evolution of the supply of reserves. The vertical red line marks the official start of the floor system. The level of reserves went from a negligible amount (NZ$20 million approx.) to around NZ$8 billion. This level remained steady until March 2020, when QE raised the supply to almost NZ$30 billion.

Figure 6 suggests that reserve supply is no longer endogenous to monetary policy under a floor system. Banks hold enough reserves, and the liquidity cost of creating new deposits no longer depends on the availability of reserves. In Figure 6a, the correlation between the interest on reserves and the supply of reserves is not significant. This correlation would be significantly negative under a corridor system like the one in the United States before 2008.

Figure 5: Reserve supply in New Zealand

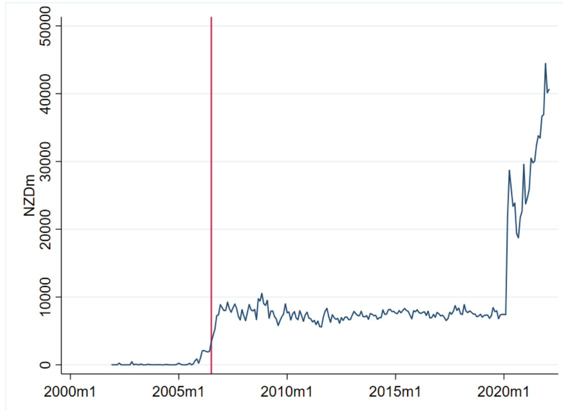
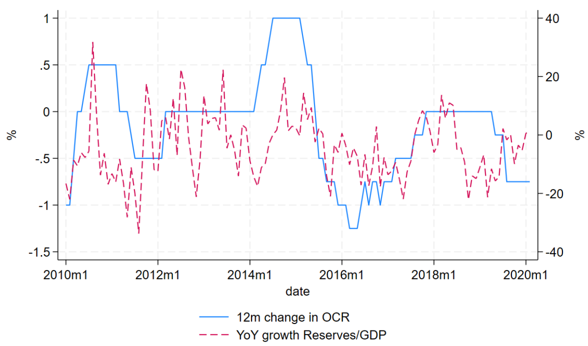
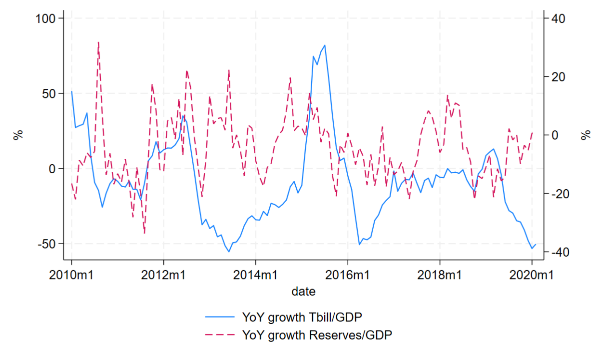


Figure 6: Correlations for NZ: Jul. 2006 - Feb. 2020

(a) IOR and reserve supply



(b) T-bills and reserve supply

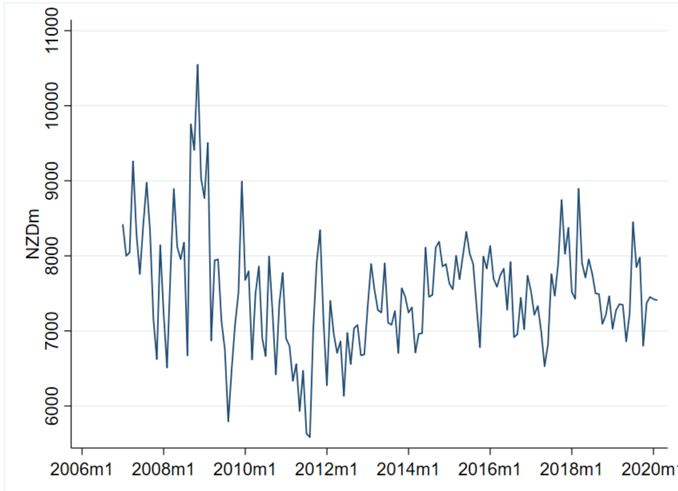


In Figure 6b, the correlation between T-bills and reserves is also not significantly different from zero, showing the disconnection between the two under a floor system.

Can we be sure to rule out any endogenous variation in reserve supply? There are two episodes in which the RBNZ injected further liquidity into the banking system, both during the financial turmoil of 2008 (in August 2007 and the Fall of 2009). These are the most likely to be driven by liquidity concerns and thus be endogenous. Figure 7 provides a closer inspection of the evolution of reserve supply. Although the RBNZ occasionally found it desirable to inject some extra reserves into the banking system -as in the two episodes mentioned- those cash additions were modest and transitory. As an extra precaution, I add the supply of reserves or deposits in the regressions to control for any out-of-order variation in their quantities.

Finally, one crucial reform happened in August 2007. A common issue with supplying too many reserves is that banks no longer need to rely on one another to access reserves,

Figure 7: Reserve supply in New Zealand: Jul. 2006 - Feb. 2020



effectively ending active trading in the interbank market. This has happened in the US since 2008 in the federal funds market, where the number of transactions has been minimal for the past decade. The RBNZ concluded that it was a good idea to avoid this outcome, as an active interbank market provides information on the health of the banks. However, once the floor system was up and running, it became clear that it encouraged some banks to hoard reserves, accumulating them without incurring any opportunity cost and, thus, without the need to go to the interbank market.

The solution to the reserve hoarding problem was a "tiering system", with reserves up to a bank's assigned tier limit earning the interest on reserves and reserves beyond that level earning 100 basis points less. The tier levels were based on banks' apparent settlement needs but collectively still amounted to the aggregate target of NZ$7 billion. The overnight interbank lending market remained active thanks to this switch to a tiered system. Banks continued to rely upon one another as lenders of first resort, turning to the RBNZ for overnight funds only as a last resort.

It is important to notice that this tiered system does not affect my identification strategy. Even though an active interbank market might suggest that banks are not fully satiated with liquidity, my strategy only needs that the overall supply of reserves is not correlated with the monetary policy rate, as they are in a scarce-reserve system. Figure 6 shows that this is the case. In contrast, the same graph for a corridor system -like the one in the US before 2008- would show a significant negative correlation between the federal funds rate and the supply of reserves/deposits.

Appendix C Robustness for results in section 2

Table 3 estimates equation (2) with data for New Zealand from July 2006 until July 2021. The dependent variable is the spread between the 3-month bank bill and the 3-month T-bill. I differentiate the dependent and independent variables to avoid concerns with stochastic trends. This avoids spurious correlations between the levels of these variables by removing random walk components in these series. All columns are estimated using OLS, with the standard errors adjusted for autocorrelation using the Newey West estimator.

Table 2: New Zealand: Determinants of liquidity premium - OLS

	Sample: 2006m7-2021m7				Sample: 2006m7-2020m2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δior_t	-0.0826	-0.0835	-0.187***	-0.187***	-0.0941*	-0.101*	-0.206***	-0.227***
	(0.0520)	(0.0529)	(0.0629)	(0.0630)	(0.0558)	(0.0542)	(0.0685)	(0.0697)
Δior_{t-1}			0.265***	0.269***			0.273***	0.295***
			(0.0763)	(0.0749)			(0.0774)	(0.0812)
Δvix_t	0.00352***	0.00256	0.00157	0.000450	0.00477**	0.00459**	0.00353	0.00370*
	(0.00133)	(0.00166)	(0.00149)	(0.00203)	(0.00193)	(0.00175)	(0.00216)	(0.00203)
Δvix_{t-1}			0.00134	0.000670			-0.000563	-0.000823
			(0.00449)	(0.00480)			(0.00641)	(0.00629)
$\Delta\log(\frac{Tbill}{GDP})_t$	-0.278**	-0.290**	-0.193**	-0.195**	-0.371**	-0.349*	-0.299**	-0.284***
	(0.124)	(0.119)	(0.0922)	(0.0767)	(0.188)	(0.184)	(0.117)	(0.108)
$\Delta\log(\frac{Tbill}{GDP})_{t-1}$			-0.0475	-0.0419			-0.0676	-0.0538
			(0.0901)	(0.0885)			(0.119)	(0.109)
$\Delta\log(\frac{Res}{GDP})_t$		0.119		0.139		0.180		0.218
		(0.0855)		(0.114)		(0.135)		(0.145)
$\Delta\log(\frac{Res}{GDP})_{t-1}$				-0.00894				-0.129
				(0.0795)				(0.0927)
Constant	-0.00646	-0.00786	-0.000266	-0.00158	-0.00864	-0.00947	-0.00253	-0.00259
	(0.00810)	(0.00833)	(0.00599)	(0.00624)	(0.0101)	(0.0103)	(0.00716)	(0.00704)
Observations	181	181	181	181	164	164	164	164

Notes: Newey-West standard errors in parentheses (6 lags). Units are hundreds of basis points. The dependent variable is the first difference of the 3-month Bank bill/T-bill spread. Independent variables are the same as in Table 1 in the main text.

In Column 1, the coefficient on the supply of T-bills is negative and significant. A one percent increase in T-bills to GDP reduces the liquidity premium by 28 basis points. The coefficient on the IOR is negative, although not statistically significant. Column 2 adds the supply of reserves as a percentage of GDP, which serves as a robustness check to the intuition that under a floor system, reserve supply is exogenous in determining the liquidity premium. The estimation shows that it does not have a significant effect, and the coefficient on the supply of T-bills is similar in magnitude and significance.

In columns 3 and 4, I add the current and lagged values of the independent variables. I do this to consider the possibility that the coefficients in columns 1 and 2 only capture a transitory effect on the liquidity premium. This is especially relevant in this case where I am using 1-month differences. It can be the case, for example, that new debt issuance by the government has a short-lived impact that fades away soon after (this is what Nagel (2016) finds for the supply variable in the US). Results show that the supply of T-bills still has a negative and significant impact, although of a smaller magnitude. Importantly, unlike the results in Nagel (2016), the lagged value is insignificant, suggesting it has a more persistent effect. The results for the IOR are the opposite. The current value of the IOR has a significant negative impact that almost entirely reverts in the following month. The negative effect of the IOR and its transitory nature is the opposite result as the one in Nagel (2016).

In columns 5-8, I replicate the first four columns but with the sample ending in February 2020. Recall that the RBNZ embarked on large-scale asset purchases after March 2020. Large-scale asset purchases involve purchasing assets in exchange for newly issued reserves. Therefore, we should no longer expect the supply of reserves to be exogenous in this situation. The estimation in columns 5-8 is a robustness check as it should be free of any effect of QE and the possible endogeneity of the supply of reserves. The results show that the impact of the supply of T-bills and the IOR is still significant.

Appendix D Regressions with U.S. data after 2008

Is the negative effect of the interest on reserves robust to using data for other countries? The following Table shows regressions of the liquidity premium for the U.S. after November 2008. The dependent variable is the spread of 3-month AA financial commercial paper and 3-month T-bills. Data for T-bill and reserve supply are from TreasuryDirect and FRED, respectively. The caveats pointed out in the main text still apply, mainly that the supply of reserves is likely to be endogenous to the different QE programs carried out by the Federal Reserve between 2009-2014. However, it is interesting to see the coefficients for the IOR, and the supply of T-bills are of the same sign as in Table 3. In particular, both the interest on reserves and the supply of T-bills have a negative effect on the liquidity premium. These results are robust to using IVs (not shown).

Table 3: U.S.: Determinants of liquidity premium, 2008m11-2020m6 - OLS

	(1)	(2)	(3)	(4)
Δioer_t	-0.363***	-0.604***	-0.361**	-0.511***
	(0.124)	(0.158)	(0.157)	(0.124)
Δioer_{t-1}			0.449***	0.403***
			(0.131)	(0.103)
Δvix_t	0.0131***	0.0119***	0.0113***	0.00813***
	(0.00293)	(0.00246)	(0.00284)	(0.00198)
Δvix_{t-1}			0.00561***	0.00453**
			(0.00184)	(0.00181)
$\Delta\log(\frac{Tbill}{GDP})_t$	-0.895***	-0.755***	-0.498***	-0.625***
	(0.223)	(0.195)	(0.139)	(0.154)
$\Delta\log(\frac{Tbill}{GDP})_{t-1}$			0.266	0.371***
			(0.167)	(0.123)
$\Delta\log(\frac{Res}{GDP})_t$		-0.932***		0.0747
		(0.343)		(0.167)
$\Delta\log(\frac{Res}{GDP})_{t-1}$				-0.495***
				(0.169)
Constant	-0.0127	-0.00209	-0.00442	2.91e-05
	(0.0137)	(0.00935)	(0.00516)	(0.00464)
Observations	140	140	139	139

Notes: Newey-West standard errors in parentheses (6 lags). Units are hundreds of basis points. The dependent variable is the first difference of the 3-month AA financial commercial paper/T-bill spread.

Appendix E Model: corridor system

Starting from the model in Section 3, one could consider a corridor system by including liquidity costs from managing deposits. In this section, I build on the framework of Curdia and Woodford (2011) that rely on a representative bank facing real intermediation and liquidity costs.

The representative bank in this economy exists because households cannot access the central bank's reserves directly. The bank, therefore, originates liquid deposits, on which they promise to pay a riskless nominal return i_t^d one period later, by either holding reserves at the central bank, M_t^d, that receive a nominal yield of i_t^m or having other assets such as loans, L_t^s, on which they earn a nominal interest rate of i_t. The bank takes all these interest rates as given. In what follows, lower-case variables denote real variables.

The representative bank faces an intermediation cost when issuing loans. In particular, the origination of l_t real loans requires costly information in the amount of $\chi_t(l_t)$, with $\chi_t', \chi_t'' \geq 0$. In addition, the bank consumes real resources in managing liquidity, $\theta(l_t, m_t^d)$, $m_t^d \equiv M_t^d/P_t$, where the cost is a positive function of the scale of operations and a decreasing function of central bank reserves held, $\theta_{lt} > 0$, $\theta_{mt} < 0$. These costs can be thought of as coming from unexpected deposit withdrawals from households. Importantly, $\theta_{mt} < 0$ means that reserves are more useful for handling liquidity costs than other assets: if they are sufficiently scarce, banks are willing to pay a higher price.

I also assume that for any scale of operations l_t, there exists a finite level of reserves $\overline{m}(l_t)$ for which $\theta_{mt} = 0$ for all $m_t^d \geq \overline{m}(l_t)$. This assumption resembles the banks' demand for reserves in the models of Poole (1968) and Afonso et al. (2020). This tries to capture that liquidity costs are increasing in the scale of operations (for example, a higher chance of unexpected withdrawals and greater precautionary liquidity demand), decreasing in reserves (for instance, as they meet regulatory requirements and facilitate intraday operations) and that with a sufficiently large amount of reserves, reserve demand by banks becomes flat once they are above their precautionary demand level, $\overline{m}(l_t)$.

Each period, the representative bank decides a scale of operation, l_t, and the level of reserves to hold at the central bank, m_t^d. It then issues real deposits to households in the maximum quantity that it can repay, taking all rates as given:

$$(1 + i_t^d)d_t^s = (1 + i_t^m)m_t^d + (1 + i_t)l_t \tag{20}$$

The bank maximizes the earnings to its shareholders (the household) each period, equal to the deposits not used to pay for loans and reserves. Therefore, the bank maximizes:

$$\Omega_t = d_t^s - m_t^d - l_t - \chi_t(l_t) - \theta(l_t, m_t^d) \tag{21}$$

The first-order conditions concerning loans and reserves are thus:

$$\frac{i_t - i_t^d}{1 + i_t^d} = \chi_t'(l_t) + \theta_{lt} \tag{22}$$

$$\frac{i_t^d - i_t^m}{1 + i_t^d} = -\theta_{mt} \tag{23}$$

The left-hand side of Equation (22) is the marginal benefit of an extra loan. The right-hand side shows the marginal cost: a higher intermediation cost. Similarly, Equation (23) equates the marginal cost of an extra reserve with its marginal benefit: a lower liquidity cost (as $\theta_{mt} < 0$).

The rate i_t^d resembles the interbank rate central banks target when implementing a corridor system. $i_t^d - i_t^m$ in Equation (23) represents the *bank's cost of liquidity.* For $m_t^d < \overline{m}_t$ and a given i_t^m, Equation (23) delivers a one-to-one relationship between the supply of reserves and the interbank rate, i_t^d. For a given i_t^m, an increase in the supply of reserves reduces the liquidity cost of banks (right-hand side of the equation) and thus reduces the premium on reserves, reducing i_t^d (in the left-hand-side). If $m_t^d \geq \overline{m}_t$, $\theta_m = 0$, banks face no liquidity cost, and the interbank rate equals the interest paid on reserves, independently of the supply of reserves. Intuitively, since reserves are abundant, banks no longer pay a premium on them.

The rate i_t^d resembles the interbank rate central banks target when implementing a corridor system (as in Curdia and Woodford, 2011). The choice of i_t^d as the central bank's policy rate can be justified as follows. In the real world, most central banks set the interbank rate at which banks trade reserve balances intraday among themselves. The interbank rate can, therefore, be seen as the rate at which banks can obtain liquid funding whenever needed. Although there is no interbank market in the model, the policy rate i_t^d captures the same idea: it is the rate at which banks can obtain liquid funding, but, in this case, from households. There are alternative ways of modeling an interbank market that gives a role to the supply of reserves (see, for example, Arce et al. (2020)), but introducing a more formal interbank market would complicate the model without improving the exposition of the underlying mechanisms.

I validate the model by showing it matches the relevant correlations if one assumes the Central Bank implements a corridor system. I show that the model under a corridor system can match the positive correlation between the interbank rate and the liquidity premium (as found in Nagel, 2016) and the positive correlation between the supply of reserves and the supply of T-bills (seen in Section 2). To perform this exercise, I assume a functional form for $\theta(l_t, m_t^d)$ and let it respond to the supply of reserves ($m_t^s < \overline{m}_t$). In addition, I assume

Table 4: Second moments under a Corridor System

Moment	Value
corr(Y_t,b_t)	0.401
corr(Y_t,m_t)	0.9517
corr(Y_t,d_t)	0.9603
corr($i_t - i_t^b$,i_t^d)	0.781

Note: Values calculated from simulating 50,000 periods and dropping the first 10,000.

that the Central Bank fixes $i_t^m = 0$; therefore, there is a one-to-one relationship between the supply of reserves and the interbank rate (captured in this case by i_t^d).

Table 4 shows the relevant correlations among the variables. Since this is not a quantitative exercise, I pay attention to the sign and significance more than their magnitude. Notice that the supply of deposits and T-bills positively correlates with the cycle. Facing a positive realization of the endowment process under a corridor system, the hike in i_t^d now needs a decrease in the supply of reserves, which reduces the supply of deposits. The increase in current inflation, in turn, decreases the real burden of the government, and the fiscal rule allows for a reduction in the debt supply. As a result, the overall supply of liquid assets decreases, and the liquidity premium increases. Therefore, a clear positive correlation exists between the interbank rate, i_t^d, and the liquidity premium, as shown in the last row of Table 4.

Appendix F Calibration of the Model

The model is calibrated with data for New Zealand at a quarterly frequency, using the sample 2006:III to 2021:III. Panel A of Table 5 shows the parameters calibrated externally. I pick a value of risk aversion of 1.5 and assume a Taylor rule parameter for inflation of 1.5, as it is common in the literature.

The rest of the parameters are calibrated under a deterministic steady state. Table 5, Panel B, shows the values for the five parameters. The targets are the illiquid rate, for which I use the yield on 6-month term deposits, the average yield on T-bills, and the OCR during

Table 5: Calibration

	A. Externally calibrated		
	Description	Value	Source
γ	Risk aversion	1.5	Standard
ψ_π	CB's response function	1.5	Standard
ρ_g	Gov's deficit	0.1	Bohn (1998)
	B. Calibrated		
	Description	Value	Target
β	Discount factor	0.994	mean(i_t)
α	Liq. preference	3.9054e-04	mean(i_t^b)
ρ_b	T-bill collateral	1.0818	mean(i_t^m)
ψ	CB's response function	1.0008	Inflation target
z	Gov's deficit	0.0142	Reserves/GDP

Notes:

the sample period. I complement this with two quantities: government debt and reserves, both scaled to GDP. I define a supply of government debt to GDP of 0.42 (OECD data, General Government debt). The ratio of reserves to GDP is obtained from the RBNZ

The calibration exercise gives a discount factor of 0.994, which is somewhat lower than usual. However, this difference accounts for the illiquidity of the intertemporal rate in the model. The liquidity preference in the household's utility function, α, takes the value of 3.9054e-04, and the value of T-bills as collateral, ρ_b, equals 1.0818. This implies that T-bills are better collateral than reserves. This is consistent with the fact that, unlike reserves, T-bills can be used as collateral for repo transactions.

Table 6 shows how the model matches the targets for prices and quantities. The last row computes the liquidity premium on government debt.

Appendix G Proof of Proposition 1

Rewrite Equation (7) in the model to get:

$$1 + i_t^d = (1 + i_t)(1 - v_{dt}) \tag{24}$$

where $v_{dt} = \frac{\alpha}{u_c(C_t)\frac{D_t}{P_t}}$ is the marginal convenience yield of deposits for the household.

Table 6: Model moments and Targets (Annualized)

Variable	Description	Data	Model
b_t	Gov debt/GDP	0.42	0.42
m_t	Reserves/GDP	0.12	0.12
i_t	Illiquid rate	4.44%	4.44%
i_t^b	Debt yield	3.25%	3.25%
i_t^m	Interest on reserves (OCR)	3.34%	3.34%
$i_t - i_t^b$	Liquidity premium	1.19%	1.19%

Notes:

In response to an endowment shock, $(1 + i_t)$ responds directly from the intertemporal Euler equation, and Equation (24) makes clear that the response of i_t^d will be less than one-to-one with the response of i_t, and the difference will be proportional to the reaction of the convenience yield. The response of the convenience yield will be given by:

$$\frac{\partial v_{dt}}{\partial Y} = -\alpha(\partial d_t/\partial Y_t)/d_t^2 \tag{25}$$

where $d_t \equiv \frac{D_t}{P_t}$. Deposits will respond depending on the change in reserves and T-bills. The difference in $\partial d_t/\partial Y_t$ under a corridor versus a floor system will come mostly from the difference in the response of reserves. Under a corridor system, the central bank reduces the supply of reserves, which will reduce deposits, and therefore $\partial Q_t/\partial Y < 0$. Under a floor system, there is no change in the supply of reserves, and the drop in deposits is smaller. Therefore, $\frac{\partial v_{dt}}{\partial Y}$ is larger under a corridor system, and the adjustment needed in i_t^d will be smaller than under a floor system.