The Liquidity Premium under a Floor System of Monetary Policy

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Abstract

Can a government exhaust the liquidity premium on its debt by borrowing too much? I show that under a scarce-reserve system, the causal impact of government debt is confounded by the endogenous dynamics of the supply of reserves (set by the central bank), which is a close substitute. I use data from New Zealand to analyze the liquidity premium under a floor system, where the interest on reserves and their supply are disentangled. I find a negative causal impact of government debt and the interest rate of monetary policy. A simple model captures the interactions between fiscal and monetary policy.

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1 Introduction

Do liquidity premiums on government bonds depend on the supply of debt? Can a government exhaust the premium by borrowing too much? The recent buildup of government debt in advanced economies to fight the Covid pandemic poses these new questions for the convenience yield literature. Isolating the role of the debt supply is challenging because the central bank endogenously alters the supply of reserves (a close substitute in the provision of liquidity services). This paper argues that the way New Zealand conducted monetary policy allows me to circumvent this endogeneity present in other data sets (including U.S. data). In particular, in July 2006, the Reserve Bank of New Zealand (RBNZ) transitioned to a floor system, where the central bank does not need to adjust the quantity of reserves to hit its monetary policy rate target. In addition, it did not reach the zero lower bound (ZLB) or did Quantitative Easing (QE) until March 2020, which is another source of endogeneity in the supply of reserves. My results show that debt supply has a negative causal impact on the liquidity premium and that the interest on reserves, stripped from its linkage to reserves supply, also reduces the liquidity premium through novel channels.

The potential exhaustion of convenience yields has significant fiscal and monetary policy implications. It is not only that these premia translate into substantial savings for the fiscal authority (Krishnamurthy & Vissing-Jorgensen, 2012), but recent papers have used convenience yields as a way to explain rates being below the growth rate of the economy (the $R < G$ condition), that allows advanced economies to run permanent fiscal deficits (Jiang et al., 2021; Mian et al., 2021). Moreover, liquidity premia interfere with short-term equilibrium interest rates (Lenel et al., 2019) and are at the center of unconventional monetary policy transmission in Krishnamurthy and Vissing-Jorgensen (2011) and Del Negro et al. (2017).

In the first part of the paper, I show that central bank reserves and the supply of T-bills have a strong positive correlation (crowding-in) when central banks conduct monetary policy under a corridor system (or scarce-reserve system). The United States and many other advanced economies implemented such a system until 2008. The central bank targets an interbank rate and supplies the amount of reserves that achieve that target through open market operations. If there is an increase in demand for liquidity by banks, the central bank prevents the interbank rate from increasing by supplying extra reserves. Similarly, if the government issued more T-bills (which also provide liquidity to banks), the central bank would adjust the supply of reserves accordingly. This correlation suggests that reserves and T-bills are likely endogenous to the business cycle. If reserves and T-bills are close substitutes, then the supply of reserves is a confounding factor for identifying the causal impact of Treasury supply on the liquidity premium.

To isolate the causal impact of the supply of government debt on the liquidity premium, one needs to look at instances where the central bank hits its monetary policy rate target without altering the supply of reserves. Monetary policy implemented through a floor system gives such an opportunity. In a floor system, the central bank supplies abundant reserves to the point where the demand for liquidity by banks no longer responds to the quantity of reserves (banks' demand for reserves becomes flat as in Poole (1968)'s model). In this scenario, the monetary policy rate used by the central bank to hit its inflation target is the interest it pays on these reserves (the IOR). Since banks do not respond to changes in the supply of reserves, the IOR and the supply of reserves are now two independent tools. Notably, the supply of reserves ceases to be endogenous to the stance of monetary policy. Therefore, a regression analysis of the liquidity premium on the supply of T-bills uncovers the causal impact of the debt supply. Including the IOR in the regression uncovers the effect of the monetary policy rate that works not through the quantity of reserves.

I carry this exercise empirically. Although the U.S. Federal Reserve has conducted something close to a floor system (since the increase in reserve supply and the interest payment on them at the end of 2008), the U.S. case is unsuitable for this purpose. This is because, for many years after 2008, it has also concurrently carried out QE. This policy, of course, casts doubt on the extent to which the supply of reserves is truly exogenous to the stance of monetary policy. For this reason, I use data for New Zealand, whose central bank transitioned to a floor system in 2006 but did not carry out QE until March 2020. The regression analysis shows that the supply of T-bills is a significant determinant of the liquidity premium and that the effect of the IOR is negative. These are novel empirical results compared to the previous literature (for example, Nagel, 2016).

A simple monetary model can explain these results. Households derive utility from consumption and holding liquid assets, either deposits or T-bills. Banks are in their flat portion of their reserves demand, and the supply of reserves follows an exogenous stochastic process (from unexpected changes in precautionary demand or household liquidity withdrawals). To achieve its monetary policy goal, the central bank only adjusts the interest paid on reserves and ensures that the reserves' supply stays above the level where banks' demand slopes downward. In the model, tightening the interest on reserves can reduce the liquidity premium on T-bills through two channels. First, it reduces the price level, which increases the real value of existing liquid assets, and this increased supply reduces the marginal value of liquidity. Second, the rise in the interest on reserves reduces the cost of liquidity for households, as the higher rate passes onto the yield on deposits. This effect reduces their willingness to pay for the liquidity of T-bills, resulting in a drop in the liquidity premium. Notice, however, that the total yield of T-bills also increases, so the government ends up paying higher yields on its debt and enjoying a lower premium. All these predictions point towards interference of monetary policy absent under a scarce-reserves system. The model is calibrated for New Zealand's data, but its implications are potentially crucial for the U.S. The FOMC's January 2019 statement says that the Committee intends to keep an abundant reserves framework going forward, where the IOR is the primary tool for its monetary policy goals and "in which active management of the supply of reserves is not required".

This paper contributes to the empirical literature on convenience yields by clarifying the impact of the supply of government debt and monetary policy. Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood et al. (2015) estimated the premium investors are willing to pay for the safety and liquidity of U.S. Treasuries compared to equivalent private debt instruments and found that a larger supply of government debt reduces the liquidity premium. However, they did not consider the role of the central bank in providing alternative liquid assets.

Nagel (2016) was the first to notice the connection with monetary policy, as the central bank sets the price of liquidity in the economy. He notes that the liquidity premium of T-bills in the United States positively correlates with the monetary policy rate. He adds the federal funds rate to the regression in Krishnamurthy and Vissing-Jorgensen (2012) and finds that the coefficient on the supply of debt loses all its significance. His interpretation is the following: deposits and T-bills must be very close substitutes in the provision of liquidity services, and, therefore, the central bank, by elastically supplying new reserves, can fully control the price of both assets. If the government suddenly supplies fewer T-bills, the central bank can step in by lowering the federal funds rate and supplying more reserves. Similarly, Vandeweyer (2021) finds that T-bills supply becomes statistically significant in regressions using data after 2008. He develops a model that explains why deposits and T-bills would no longer be perfect substitutes.

I show that the positive correlation between reserves and T-bills does not support the crowding-out between reserves and T-bills at the center of these papers' mechanism. I contribute to clarifying the role of monetary policy by choosing a setup where the supply of reserves is exogenous. My model complements Nagel's (2016) analysis by highlighting new channels through which the monetary policy rate can impact the liquidity premium. My analysis also complements Vandeweyer's (2021) by showing that under an abundant-reserve system, it is natural to expect the supply of T-bills to become statistically significant, regardless of the degree of substitutability between debt and deposits.

I choose to rely on a monetary model as it better highlights the role of liquidity premia for both deposits and government bonds. Lenel et al. (2019) also build a monetary model. However, they do not look at the determination of the liquidity premium of government debt and the interactions between the fiscal and the monetary authority. Floor systems and monetary policy under abundant liquidity have been studied mainly in the last decade (see Curdia and Woodford, 2011; Cochrane, 2014; Canzoneri et al., 2017; Afonso et al., 2020), and recent attempts have been made for New Keynesian models to include a role for liquidity (see Piazzesi et al., 2021; Benigno & Benigno, 2021; and Bianchi and Bigio, 2021). Their focus, however, is not on convenience yields and their magnitude implication for monetary and fiscal policy. Finally, my paper also has implications for the literature studying the role of liquidity supply in monetary policy transmission (see Drechsler et al. (2018) for a review).

The paper proceeds as follows. Section 2 shows the empirical exercise using data from New Zealand, while Section 3 runs counterfactual exercises highlighting monetary and fiscal policy interactions. Section 4 concludes.

2 Empirical analysis

In this section, 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 here is that, since the maturity and 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.

The challenge here is to find what assets in the case of New Zealand are similar to T-bills in maturity and credit risk. In this section, I use two alternatives: 3-month bank bills and 6-month term deposits. The Appendix describes the data sources for these series.

Bank bills are a common investment in Australia and New Zealand: it is simply a promise by the borrower to pay the amount specified (face value) at the date specified. It is considered a safe investment because they are "accepted" (guaranteed) by a bank. In accepting the bank bill, the bank undertakes to make payment at maturity, irrespective of the repayment ability of the borrower. Investors can buy bank bills from a bank, for an agreed face value, an agreed term, and a quoted rate of interest. The bank bills are then endorsed by the bank to acknowledge the change in ownership, transferring the ownership to the buyer. 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.

The spread between term deposits rates and T-bill rates are one of the measures used in Krishnamurhty and Vissing-Jorgensen (2012) for US data. Term deposits in New Zealand, similar to the US, are a safe investment where investor 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 to do so. Therefore, the spread should account for the liquidity provided by the T-bill. The Reserve Bank of New Zealand regularly publishes weighted averages of rates in 6-month term deposits of NZ$10,000 and above.

The liquidity premium measured with these two assets is sizeable. The bank bill has a yield 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 at any time during the term of the instrument, while the investment in the term deposit is locked in for the whole term. Standard deviations are high for both measures: 24 and 80 basis points, respectively.

2.1 Empirical model

Next, I explain my empirical strategy to isolate the causal impact of Treasury supply on the liquidity premium. A good starting point is to consider the following regression:

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

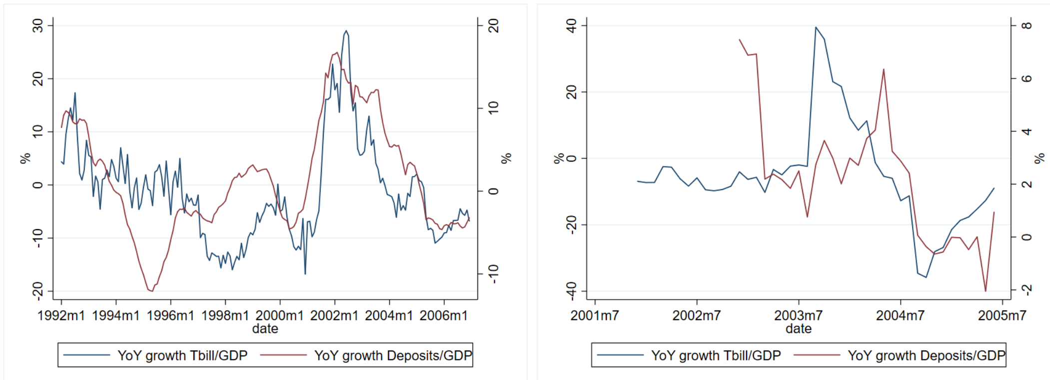
where LP_t is the liquidity premium of T-bills, FFR_t is the level of the monetary policy rate set by the central bank (the federal funds rate in the case of the United States) and $(Tbills/GDP)_t$ is the total supply of T-bills. Nagel (2016) estimates this regression for the United States with data from 1991 to 2011, when the U.S. Fed was mostly using 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 monetary policy decisions by the central bank. The explanation would go as follows: under scarce reserves, the level of the FFR is linked ono-to-one with the supply of reserves, which in turn determine the cost of issuing deposits by banks. Deposits and T-bills must be very close substitutes in the provision of liquidity services and therefore the central bank, by elastically supplying new reserves, can fully control the price of both assets. For example, if the government were to suddenly supply less 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 that is continually offsetting new issuances of T-bills by an opposite change in the supply of deposits. At the end, 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 implement a corridor system shows that T-bills and deposits do not crowd-out each other, but rather they are crowded-in. In Figure 1a I show the correlation between T-bills supply and deposits supply for the United States between 1992 and 2006. The correlation between the yearly growth rates of T-bills and Deposits is 0.62, significant at the 1% level. For New Zealand the sample is shorter, but a positive correlation still emerges (0.44, significant at the 1.4% level, for December 2001 to June 2005). The crowding-in is also consistent with the result in Krishnamurthy and Vissing-Jorgensen (2015), who estimate the extent to which Treasury debt crowds out short-term liabilities by the financial sector. They find an economically significant crowding out, but it works through Treasury supply crowding out non-checkable short-term debt (time and savings deposits) rather than liquid deposits like checking accounts.

Figure 1 suggests that both the supply of deposits and the supply of T-bills are endogenous and respond similarly to the business cycle. The positive correlation between supply of deposits and T-bills implies that the former is a confounding factor when estimating the causal impact of

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

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



the supply of T-bills on the liquidity premium. Therefore, to isolate the causal impact of T-bills on their liquidity premium, we need to look at instances where the central bank does not alter the supply of reserves to achieve its target.

Based on this evidence, assume the following decomposition for the federal funds rate:

$$FFR_t = \gamma_1 i_t^m + \gamma_2 M_t^s + \gamma_3 (Tbill/GDP)_t \tag{2}$$

where M_t^s is the supply of reserves and i_t^m is the interest paid on reserves (IOR) by the central bank. The federal funds rate is the rate at which banks borrow reserves from other banks. Under a scarce-reserve system, banks are willing to pay a premium for the liquidity of reserves. As they operate in the downward-sloping portion of their demand for liquidity, a larger supply of reserves lowers the willingness to pay for them, and so $\gamma_2 < 0$. As T-bills can also provide liquidity, they will have a similar effect, and therefore γ_3 will also be negative. In reality, since the Fed sets a target for the federal funds rate, whenever the government issues more T-bills, the central bank needs to issue more reserves to prevent money market rates to go over the target.

The true model for the liquidity premium would then be:

$$LP_t = \beta_0 + \beta_1 \gamma_1 i_t^m + \beta_1 \gamma_2 M_t^s + (\beta_1 \gamma_3 + \beta_2)(Tbill/GDP)_t + \epsilon_t \tag{3}$$

Equation (3) shows that the effect of the supply of debt can be decomposed into a direct effect (for which Nagel (2016) estimates $\hat{\beta}_2 = 0$), and an effect working through their substitutability with reserves ($\beta_1 \gamma_3$, and we know $\hat{\beta}_1 > 0$).

As explained above, to isolate the causal impact of T-bills on their liquidity premium, we need to look at instances where the central bank does not need to alter the supply of reserves to achieve its target. I claim that such an opportunity is given by a floor (or abundant-reserve) system. Under a floor system, the central bank issues abundant reserves, at or beyond the point were reserve demand by banks becomes flat (and does not respond to supply). This can be understood through the model of banks' reserve demand in Poole (1968) or Afonso et al. (2020). In this model, banks demand reserves only to meet reserve requirements, and there are no frictions in the interbank market. At high levels of aggregate reserves, demand is flat, 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 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 can be used for some other goal. Importantly, the supply of reserves is no longer endogenous to the conduct of monetary policy and clears up this confounding factor of the impact of debt supply.

As monetary policy implemented through a floor system does not work through the supply of deposits, I can assume that $\gamma_2 = 0$ in (3). Therefore, I estimate the following regression:

$$LP_t = \alpha_0 + \alpha_1 i_t^m + \alpha_2 (Tbill/GDP)_t + \epsilon_t \tag{4}$$

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 no longer involves a decrease in the supply of reserves. Therefore, it captures the effect of the level of interest rates on investors' demand for liquidity. The expected sign of $\widehat{\alpha}_1$ is thus negative. The coefficient $\widehat{\alpha}_2$ will capture the causal effect of the supply of T-bills, no longer confounded by the response of the supply of reserves.

The Fed 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 has coincided with the conduct of QE, so it does not allow me to disentangle between the two. For that reason, I study the liquidity premium under a floor system with data from New Zealand. In July 2006, the Reserve Bank of New Zealand (RBNZ) began the transition from a symmetric channel system of monetary policy implementation to a floor system (see the Appendix for a more detailed description of this transition and its main elements). The level of reserves went from a negligible amount (NZ$20 million approx.) 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 Official Cash Rate) was set equal to the interbank rate. Importantly, New Zealand did not reach the zero lower bound nor conducted QE until the Covid crisis in 2020 (where reserves supply was raised to almost NZ$30 billion), and so it is an ideal scenario to study a floor system.

Data for New Zealand suggests that reserves 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. Under a scarce-reserve system, the correlation between the federal funds rate and the supply of reserves is significantly 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 describes the data and show these correlations graphically. It also addresses two specific episodes in which the RBNZ injected liquidity into the banking system, which were most likely driven by liquidity concerns and therefore endogenous.

2.2 Results

I estimate equation (4) via instrumental variables with data from July 2006 until July 2021. The dependent variable is the 6-month term deposit spread and the independent variables are the interest on reserves, the supply of T-bills, the supply of deposits, and the VIX index. The supply of deposits accounts for the few instances where the RBNZ injected reserves for endogenous reasons. The regressions in the Appendix show that results are robust to use the supply of reserves instead of the supply of deposits. The VIX index intends to capture any global uncertainty that might encourage investors to prefer government securities over private assets. As New Zealand is a small open economy, it should be a good proxy for financial distress.

Instrumental variables are important since an unobserved shock to the liquidity premium not accounted for in the explanatory variables could be correlated with interest rates or the supply variables. For example, a rise in the liquidity premium due to an unobservable liquidity demand shock may prompt the central bank to lower interest rates in the same month, leading to reverse causality from the liquidity premium to the interest rate and a downward biased estimate of the interest rate coefficient. In the Appendix I show that the results are robust to using the 3-month bank bill as the dependent variable, and also to running the regression in first differences to avoid concerns with stochastics trends. Standard errors are adjusted for autocorrelation using the Newey West estimator.

To instrument the interest on reserves I use futures prices, in the same way as in Piazzesi and Swanson (2008). In particular, I use the generic future contract for the 3-month bank bill, available in Bloomberg. Although with a premium, this yield tracks the dynamics of the official cash rate closely. These are futures contracts that settle at the end of each month based on the average rate that prevails during that month. The futures price before expiration is a risk-adjusted forecast of the average rate that prevails during the expiration month. Used as an instrument, the futures price in months prior to the expiration month should therefore be highly correlated with the average policy rate during the expiration month.

To instrument the supply variable, I use nonlinear functions of the ratio of total debt to GDP. Greenwood et al. (2015) and Nagel (2016) use month dummies to exploit the strong seasonality in T-bill supply in US data. This arises from seasonal fluctuations in tax receipts that are plausibly exogenous and immune to the reverse causality problem. This does not seem to work for New Zealand data. Nonlinear functions of total debt to GDP, instead, exploit the positive correlation between total debt and its maturity structure. This instrument has been used, for example, in Krishnamurthy and Vissing-Jorgensen (2012).

Table 1 shows the results. Even-numbered columns restrict the sample to end on February 2020, to make sure results are not driven by the Covid shock. Overall, the coefficient on T-bill supply is negative and significant. This, again, is the effect of debt supply on the liquidity premium when the confounding factor of reserves is absent. Interestingly, the coefficient on the interest on reserves is negative and significant, which is the opposite as in Nagel (2016). The model will be able to explain this negative effect: an increase in the interest on reserves will induce banks to increase the interest paid on deposits. Households will face therefore a lower cost of liquidity, and their willingness to pay for T-bills then will be lower.

The results in Columns 1 and 2 assume that the supply of deposits is exogenous. To be sure, in Columns 3 and 4 I replicate the first two columns with an instrument for the supply of deposits. The instrument is a nonlinear function of the supply of T-bills, in addition to the supply of total debt being the instrument of the supply of T-bills. The results show that the supply of T-bills still has a significant impact on the liquidity premium, and this time the magnitude of the effect is comparable to the one in Krishnamurthy and Vissing-Jorgensen (2012). A one percent increase in the supply of T-bills reduces the liquidity premium in 60 basis points. If I exclude the Covid crisis period, the effect is 40 basis points (column 4). The IOR also keeps its magnitude and significance. A one percent increase reduces the liquidity premium in 53 basis points, and 47 if I end the sample in February 2020.

In Columns 5 and 6 I replicate Columns 3 and 4 but this time including the level of the U.S. federal funds rate. This intends to capture the fact that New Zealand is a small open economy, and thus the price investors are willing to pay for local-dollar assets might be affected by the price of the U.S.-dollar liquidity. This is important as is well known that the U.S.-dollar is the global safe and liquid asset for global investors. Columns 5 and 6 show that my results are not affected once I control for this fact.

Importantly, 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 20% of the OLS bias) at a significance level of 5%.

3 Monetary and fiscal policy interactions

In this section, I set up a model to explore interactions between monetary and fiscal policy. The details of the model are described in the Appendix, and here I sketch the main elements. In

Table 1: New Zealand: Determinants of liquidity premium - 2SLS

	(1)	(2)	(3)	(4)	(5)	(6)
ior_t	-0.595***	-0.399***	-0.533***	-0.472***	-0.558***	-0.483***
	(0.172)	(0.109)	(0.0873)	(0.0801)	(0.108)	(0.0914)
$\log(\frac{Tbill}{GDP})_t$	-1.050*	-0.312	-0.606***	-0.406*	-0.963***	-0.654**
	(0.575)	(0.325)	(0.222)	(0.208)	(0.340)	(0.314)
$\log(\frac{Dep}{GDP})_t$	-6.972**	-3.255*	-6.244***	-4.578***	-7.912***	-5.783***
	(2.794)	(1.864)	(1.484)	(1.355)	(1.978)	(1.648)
vix_t	0.00869	0.00524	0.00330	0.00402	-0.000303	-0.000559
	(0.00945)	(0.00988)	(0.00779)	(0.00901)	(0.00825)	(0.00814)
$USfedfunds_t$					-0.168*	-0.114
					(0.0949)	(0.0928)
Constant	4.968***	3.815***	5.503***	4.729***	6.078***	5.162***
	(1.126)	(0.900)	(0.820)	(0.735)	(0.960)	(0.740)
Instruments for:						
OCR	Y	Y	Y	Y	Y	Y
Tbill supply	Y	Y	Y	Y	Y	Y
Dep supply	N	N	Y	Y	Y	Y
Weak instruments test						
CD stat	9.22	10.25	18.3	16.67	16.15	14.03
SY critical value	5.57	5.57	5.56	5.56	5.56	5.56
Sample ends Feb. 2020	N	Y	N	Y	N	Y
Observations	181	164	181	164	181	164
R-squared	0.289	0.670	0.419	0.641	0.400	0.632

Notes: Data are at monthly frequency. Units are hundredth of basis points. Newey-West standard error in parenthesis (6 lags) *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the monthly Term deposit/Tbill spread. A CD stat greater than the Stock and Yogo critical value rejects weak instruments (with bias greater than 20% of OLS bias).

the model the liquidity premium arises at the household level, who derive convenience services from either deposits (issued by banks) or T-bills. This is slightly different from the discussion in Section 2.1, where the premium showed up at the banks' level, which derived liquidity from reserves or T-bills. I do this because it will allow me to compare the implications with those in Nagel (2016) and Vandeweyer (2021). In addition, reserves are one of the determinants for the supply of deposits, and it is reasonable to assume that ultimately banks are just intermediaries who want to serve households. Moreover, the households combine liquidity preferences with consumption-saving decisions, which are also important for monetary policy. Overall, the novelty of the analysis is that the interactions between the monetary and the fiscal authority occur through the liquidity service of the assets in the household's portfolio.

This is an endowment economy with households, banks, a government, and a central bank. The representative household obtains utility from consumption and a real stock of liquid assets, Q_t:

$$\mathbb{E}_0 \sum_{t=1}^{\infty} \beta^t [u(C_t) + \alpha \log(Q_t)] \tag{5}$$

$$\text{where } Q_t = \left[(1-\lambda_t) \left(\frac{D_t}{P_t} \right)^{\rho} + \lambda_t \left(\frac{B_t^h}{P_t} \right)^{\rho} \right]^{\frac{1}{\rho}} \tag{6}$$

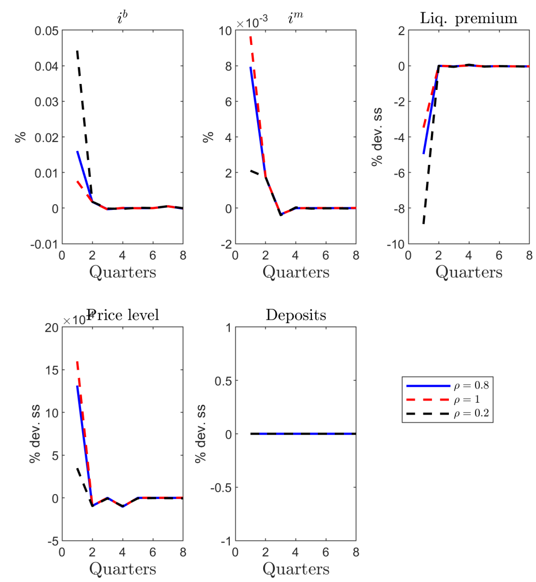
$\frac{D_t}{P_t}$ denotes real balances of deposits and $\frac{B_t^h}{P_t}$ denotes the real value of the household's T-bill holdings. P_t is the nominal price of the consumption good. These liquidity benefits arise from some unmodeled use in intra-period transactions. Both deposits and T-bills have a 1-period maturity. The parameter ρ controls the elasticity of substitution between T-bills and deposits. With $\rho = 1$, T-bills and deposits are perfect substitutes. If $0 < \rho \leq 1$ they are imperfect substitutes. The parameter λ_t, allows for differences over time in the relative contribution of T-bills and deposits to the stock of liquidity.

The liquidity premium is the spread between the intertemporal rate that governs consumption/savings decisions and the rate on T-bills. The latter is lower because of the marginal utility service provided by the real stock of liquid assets. The spread will depend negatively on the quantity of both T-bills and deposits. The government provides T-bills through an exogenous process and the banks provide deposits. Banks issue deposits because they are a cheaper source of funding than equity capital. However, deposits are costly to produce, and this cost is negatively related to the supply of reserves set by the central bank. The central bank has a price level target, P^*. Under a floor system, the central bank supplies enough reserves up to the point where they no longer affect the supply of deposits, and the central bank achieves its target solely through setting the interest on reserves. This way, both the interest rate and the supply of reserves are two independent policy tools. Importantly, the central bank can alter the interest on reserves without changing the supply of reserves.

3.1 Shock to the supply of debt

First, I consider an exogenous increase in the supply of government debt. In New Zealand data, 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. This large standard deviation is influenced by the debt issuance in response to the global financial crisis. I consider an increase in the debt to GDP ratio of 1.08% over a year. The blue line in Figure 2 compares the impulse responses of the yield on T-bills, the liquidity premium, the price level, and deposits for a value of $\rho = 0.8$.

Figure 2: Positive debt supply shock - floor system

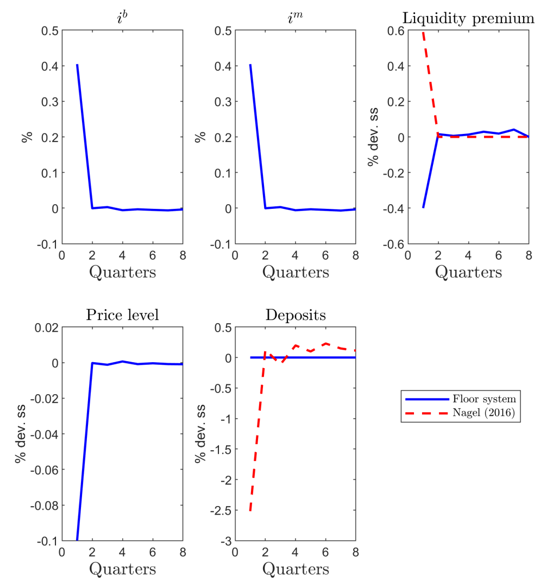


When the government issues new debt, the monetary policy rule calls for a rise in i_t^m as the price level rises. Alternatively, from a liquidity preference perspective, the central bank has to lower the cost of liquidity of households to encourage them to hold the new debt. This is achieved through an increase in the interest on reserves, which reduces the cost of liquidity of deposits as banks pass the extra yield on reserves to deposits. This will make households less willing to pay for the liquidity of a T-bill. Since in a floor system this can be achieved without altering the supply of reserves, there is no change in the supply of deposits. The final effect is a drop in the liquidity premium, coming both from the direct effect of extra supply of debt and the indirect effect of the higher interest on reserves.

In Nagel (2016)'s model, the central bank would also raise the interest rate, but this would need a reduction in reserves and in the supply of deposits. This drop in the supply of deposits would offset the increase in debt supply; if they are perfect substitutes, then there would be no change in overall liquidity and no change in the liquidity premium. This is how he explains that in his regressions the supply of debt has no statistical significance. Notice, however, that this mechanism predicts a negative correlation between debt and reserves, which does not fit the data.

Figure 2 also shows the responses for different degrees of substitutability between deposits and T-bills. I plot the responses for $\rho = 0.2$ (low substitutability between deposits and T-bills) and $\rho = 1$ (perfect substitutability) along with $\rho = 0.8$. The purpose of this Figure is to show that the supply of debt has a causal impact on the liquidity premium regardless of the degree of substitutability between deposits and bonds. Vandeweyer (2021) extends the regressions in Nagel (2016) and finds that the supply of debt has become statistically significant in the United States after 2008. This

Figure 3: Monetary Policy tightening - floor vs. scarce-reserve system



leads him to conclude that it must be because deposits and T-bills are no longer perfect substitutes. Figure 2 shows that debt becoming statistically significant once the United States transitioned to an abundant-reserve system cannot be used to conclude on the degree os substitutability between T-bills and deposits.

3.2 Shock to the policy rate

In this subsection I consider an exogenous tightening of the interest on reserves. The monetary policy shock in the model is assumed to follow an iid process. The 25 basis point shock increases the interest paid on reserves, with everything else being equal, by 1% at annual rates. In Figure 3 I set the parameter ρ at 0.8, reflecting a high degree of substitutability. For the sake of comparison, the red line shows the same responses in the model of Nagel (2016).

In the current model of a floor system, the hike in the interest on reserves has two effects. First, it increases the yield earned by banks on holding reserves, which they pass-through to a higher yield on deposits. This lowers the cost of liquidity for households and, therefore, their willingness to pay for the liquidity provided by T-bills. Second, it lowers the price level, increasing the real value of liquid assets for households. This, in turn, reduces the marginal value of liquidity. The combined effect of these two forces lowers the liquidity premium on T-bills, as shown by the solid blue line in Figure 3.

These two channels are absent in Nagel (2016). In his model, the sign of the effect of the policy rate (which in a corridor system is different from the interest on reserves) hinges critically on the degree of substitutability of liquid assets. This is because the hike in the policy rate is linked one-to-one with a reduction in the supply of reserves. The reduction in the supply of deposits (coming from the reduction in the supply of reserves) reduces the liquidity aggregate, Q_t. Accordingly, the liquidity premium of T-bills rises, the more the closer substitution between the two liquid assets.

Overall, this exercise shows that a monetary policy tightening can have a negative impact on the liquidity premium. This has two important implications. First, for the fiscal outlook of the government. Notice that the yield on T-bills rises along with the interest on reserves. The government is paying a higher yield and enjoying lower savings due to a lower convenience yield. Second, for monetary policy: under a scarce-reserve system, the monetary policy rate affected the liquidity premium of all liquid assets in the same direction, but under a floor system that is no longer true for the interest on reserves.

4 Conclusions

This paper has shown that the supply of government debt negatively impacts the liquidity premium. A government that borrows too much can reduce the premium and eventually exhaust it. From the perspective of fiscal capacity, too much borrowing can reduce convenience yields, increasing R possibly above G, and thus rendering permanent deficits unsustainable (Mian et al., 2021; Jiang et al., 2021).

As the number of advanced economies implementing an abundant-reserves system has grown, it is even more critical to understand how this new system has changed this and other linkages between monetary and fiscal policy. Previous results linking the liquidity premium to central bank decisions under a scarce-reserve system no longer apply under a floor system. The positive correlation between the monetary policy rate and the liquidity premium likely reverses under a floor system.

References

Afonso, Gara, Kyungmin Kim, Antoine Martin, Ed Nosal, Simon Potter, and Sam Schulhofer-Wohl, 2020. "Monetary Policy Implementation with an Ample Supply of Reserves", Finance and Economics Division Series 2020-020. Washington: Board of Governors of the Federal Reserve System.

Benigno, Gianluca and Pierpaolo Benigno, 2021. "Interest, Reserves and Prices", Working Paper.

Bianchi, Javier and Saki Bigio, 2021. "Banks, Liquidity Management and Monetary Policy", *Econometrica*, forthcoming.

Cao, Dan, Wenlan Luo and Guangyu Nie, 2020. "Global DSGE Models", Working Paper.

Canzoneri, Matthew, and Behzad Diba, 2005. "Interest rate rules and price determinacy: The role of transactions services of bonds", *Journal of Monetary Economics* 52, 329-343.

Canzoneri, Matthew, Robert Cumby and Behzad Diba, 2017. "Should the Federal Reserve Pay Competitive Interest on Reserves?", *Journal of Money, Credit and Banking* 49(4), 663-693.

Cochrane, John, 2014, "Monetary policy with interest on reserves", *Journal of Economic Dynamics & Control* 49, 74-108.

Cúrdia, Vasco and Michael Woodford, 2011, "The central bank balance sheet as an instrument of monetary policy", *Journal of Monetary Economics* 58 (1), 54-79.

Del Negro, Marco, Gauti Eggertsson, Andrea Ferrero and Nobuhiro Kiyotaki, 2017. "The Great Escape? A Quantitative Evaluation of the Fed's Liquidity Facilities", *American Economic Review*, 107(3), 824-857.

Drechsler, Itamar, Alexi Savov and Philipp Schnabl, 2018. "Liquidity, Risk Premia, and the Financial Transmission of Monetary Policy", *Annual Review of Financial Economics* 10, 309-28.

Greenwood, Robin, Sam Hanson and Jeremy Stein, 2015, "A comparative-advantage approach to government debt maturity", *Journal of Finance* 70, 1683-1722.

Jiang, Zhengyang, Hanno Lustig, Stijn van Nieuwerburgh and Mindy Xiaolan, 2021. "The US Public Debt Valuation Puzzle", Working Paper.

Krishnamurthy, Arvind and Annette Vissing-Jorgensen, 2011. "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy", *Brookings Papers on Economic Activity*, Fall, 215-287.

_____, 2012, "The aggregate demand for Treasury Debt", *Journal of Political Economy* 120, 233-267.

_____, 2015, "The impact of Treasury supply on financial sector lending and stability", *Journal of Financial Economics* 118, 571-600.

Lenel, Moritz, Monika Piazzesi and Martin Schneider, 2019, "The short rate disconnect in a monetary economy", *Journal of Monetary Economics* 106, 59-77.

Mian, Atif, Amir Sufi and Ludwig Straub, 2021. "A Goldilocks Theory of Fiscal Policy", Working

Paper.

Nagel, Stefan, 2016, "The liquidity premium of near-money assets", *Quarterly Journal of Economics* 131, 1927-1971.

Piazzesi, Monika, Ciaran Rogers and Martin Schneider, 2021, "Money and banking in a New Keynesian Model", Working Paper.

Piazzesi, Monika and Eric Swanson, 2008. "Futures Prices as Risk-Adjusted Forecasts of Monetary Policy", *Journal of Monetary Economics* 55, 677-691.

Poole, William, 1968. "Commercial Bank Reserve Management in a Stochastic Model: Implications for Monetary Policy", *Journal of Finance* 23(5), 769-791.

Vandeweyer, Quentin, 2021. "Treasury Debt and the Pricing of Short-Term Assets", Working Paper.

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-months yields on T-bills are calculated from auction results published by the Debt Management Office of the New Zealand's Treasury. When there is more than one instrument offered, I take the weighted average of successful yields.

Supply of T-bills and deposits: the amount of T-bills outstanding are published at the monthly frequency by the Debt Management Office of the New Zealand's Treasury. Series are at market value. The supply of reserves by the central bank are obtained from the RBNZ's balance sheet (see statistics, table R2). The supply of deposits corresponds to households deposits at registered banks, available at the RBNZ's statistics (see Household balance sheet, table C22).

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

Other: the VIX index and the US 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 US T-bills (see Figure 1 in the main text) was obtained from Treasurydirect. US deposit supply in the same Figure corresponds to the sum of checking and savings accounts in Table 4 in H.6 release (see FRED).

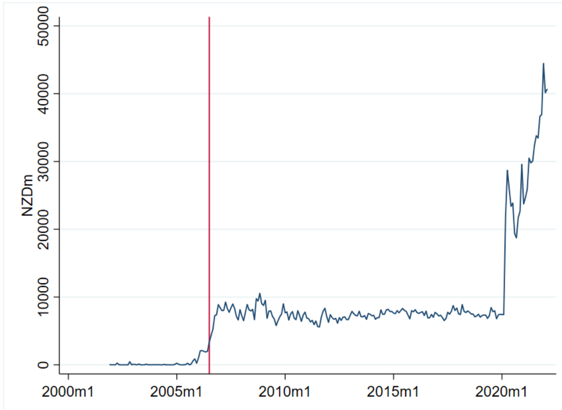
Appendix B Monetary policy in New Zealand

From 1999 until July 2006, the Reserve Bank of New Zealand (RBNZ) relied upon 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 in such a regime banks' overnight settlement balances (i.e., reserves) bore an opportunity cost, 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 in the remainder of the day a bank faced any real-time liquidity need, it would rely on credit from the RBNZ instead of waiting to settle their net balances at the end of each day.

The disadvantage of the RTGS is that exposes the central bank to credit risk. To avoid that risk

Figure 4: Reserve supply in New Zealand



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

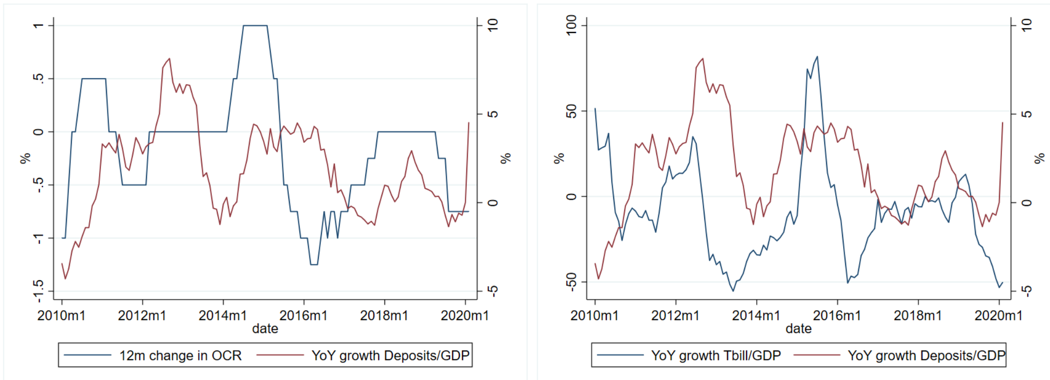
The RBNZ conducted a review of its liquidity management regime in 2005 and announced a new system in early 2006. Recognizing the danger of losses, the RBNZ encouraged banks to rely on overnight settlement balances (reserves), instead of intraday repos, to meet their settlement needs. With that end in 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 in reserves between July and October. Concurrently, it increased the interest paid on those reserves in 25 basis points (made in five-points increments), to encourage banks to hold them. Next, the RBNZ stopped providing intraday repos. At the end, the RBNZ achieved the two key components of a floor system: the interest rate on reserves was set equal to the policy rate and banks were well supplied, if not satiated, with liquidity.

Figure 4 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 was kept steady until March 2020, when QE raised the supply to almost NZ$30 billion.

Figure 5 suggests that deposit 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 5a the correlation between the interest on reserves and the supply of deposits is not significant. Under a corridor system like the one in the United States before 2008, this correlation would be significantly negative. In Figure 5b the correlation

Figure 5: Correlations for NZ: Jul. 2006 - Feb. 2020

(a) Interest on reserves and deposit supply (b) T-bills and deposit supply



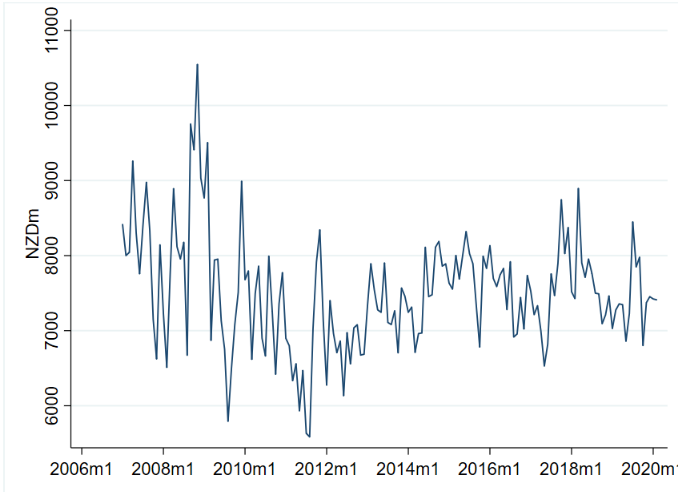
between T-bills and deposits is also not significantly different from zero, showing the disconnection between the two under a floor system.

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 in the Fall of 2009). These are the most likely to be driven by liquidity concerns and thus be endogenous. Figure 6 provides a closer inspection for 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, in order to control for any out-of-order variation in their quantities.

Finally, one important 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, effectively ending active trading in the interbank market. This is what has happened in the US since 2008 in the federal funds market, were the number of transactions has been at a minimum for the past decade. The RBNZ concluded that it was a good idea to avoid this outcome, as an active interbank market provides one more source of information on the health of the banks. However, once the floor system was up and running it became clear that it was encouraging at least some banks to hoard any surplus 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 themselves based on banks' apparent settlement needs, but collectively still amounting to the aggregate target of NZ$7 billion. Thanks to this switch to a tiered system, the overnight interbank lending market remained active. Banks continued to rely upon one another as lenders of first resort, turning to the RBNZ for overnight funds only as a last

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



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 actually are in a scarce-reserve system. Figure 5 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 Additional empirical results

Table 2 estimates equation (4) 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. To avoid concerns with stochastic trends I difference both the dependent and the independent variables. This avoids spurious correlation 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.

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 in 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. First, it serves as a robustness check to the intuition that under a floor system reserves supply are exogenous in the determination of 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

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. Dependent variable is the first difference of the monthly averages of the Bank bill/T-bill spread. *** p<0.01, ** p<0.05, * p<0.1

to consider the possibility that the coefficients in columns 1 and 2 are only capturing 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 in fact what Nagel (2016) find for the supply variable in the US). Results show that the supply of T-bills still has a negative and significant impact, although of smaller magnitude. Importantly, and unlike the results in Nagel (2016), the lagged value is not significant, 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 fully 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 in large scale asset purchases after March 2020. Large scale asset purchases involve the purchase of assets in exchange of newly issued reserves. Therefore, in this situation we should not expect the supply of reserves to be exogenous anymore. The estimation in columns 5-8 serves as 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 effects of the supply of T-bills and the IOR are still significant.

The magnitude of the effect of the supply of T-bills is lower than in Krishnamurthy and Vissing-Jorgensen (2012). In the former, their Table 2 shows that a one percent increase in debt to GDP reduces the price of liquidity in 69 basis points (column 6). Their measure of liquidity premium is the spread between term deposits and T-bills. As for the effect of the monetary policy rate, in Nagel (2016) a one percent increase in the federal funds rate increases the liquidity premium in 10 basis points. My results show that the sign of the IOR is the opposite, and it has a slightly larger magnitude.

Appendix D Model

It is an endowment economy-representative agent model comprised of households, who have a special demand for liquid assets (deposits and T-bills); a financial sector (banks, for short) who provide deposits by accumulating central bank reserves and other assets; a fiscal authority who every period supplies liquid securities; and a central bank that conducts monetary policy who targets a price level. I choose to rely on a monetary model with flexible prices as it better highlights the role of liquidity premia for both the central bank and the government.

D.1 Households

This sector follows Nagel (2016) closely, which will facilitate comparisons with his results. There is a single perishable consumption good with endowment stream $\{Y_t\}$. The endowment follows an exogenous process:

$$\log Y_{t+1} = \rho_y Y_t + \epsilon_{t+1} \quad , \epsilon_t \sim N(0, \sigma^2) \tag{7}$$

The representative household seeks to maximize the objective:

$$\mathbb{E}_0 \sum_{t=1}^{\infty} \beta^t [u(C_t) + \alpha \log(Q_t)] \tag{8}$$

where C_t is consumption and Q_t is a real stock of liquid assets that the household draws service flows from. Liquidity services are supplied by money in the form of demand deposits and near-money in the form of T-bills issued by the government. Stock of liquidity is the CES aggregate:

$$Q_t = \left[(1-\lambda_t) \left(\frac{D_t}{P_t} \right)^{\rho} + \lambda_t \left(\frac{B_t^h}{P_t} \right)^{\rho} \right]^{\frac{1}{\rho}} \tag{9}$$

where $\frac{D_t}{P_t}$ denotes real balances of deposits and $\frac{B_t^h}{P_t}$ denotes the real value of the household's T-bill holdings. P_t is the nominal price of the consumption good. These liquidity benefits arise from some unmodeled use in intra-period transactions. A model period is one quarter, and T-bills have a one-period maturity.

The parameter ρ controls the elasticity of substitution between T-bills and deposits. With $\rho = 1$, T-bills and deposits are perfect substitutes, and the composition of the aggregate liquidity supply is irrelevant. If they are imperfect substitutes, then $0 < \rho \leq 1$. The parameter λ, allows for differences in the relative contribution of T-bills and deposits to the stock of liquidity.

Households optimize subject to the flow budget constraint:

$$\begin{aligned} D_t + B_t^h + k_t A_t - L_t + P_t C_t &= D_{t-1}(1 + i_{t-1}^d) + B_{t-1}(1 + i_{t-1}^b) \\ &+ k_{t-1}(A_t + P_t Y_t) - T_t - L_{t-1}(1 + i_{t-1}) + \Omega_t \end{aligned} \tag{10}$$

where B_t^h are the holdings of T-bills. 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_t^b is the T-bill yield, i_t^d is the interest rate on demand 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 with respect to consumption yields the intertemporal Euler equation

$$1 + i_t = \frac{1}{\beta}\left\{\mathbb{E}_t\left[\frac{u_c(C_{t+1})}{u_c(C_t)}\frac{P_t}{P_{t+1}}\right]\right\}^{-1} \tag{11}$$

where u_c denotes the first derivative of $u(.)$. Equation (11) governs the household's intertemporal decisions, and thus this is the rate that the monetary authority is looking to affect. However, as explained below, the central bank's policy rate is the rate on deposits, which will carry a convenience yield and will trade below the i_t.

The first-order conditions with respect to real liquid asset balances are:

$$\frac{\alpha(1-\lambda_t)(\frac{D_t}{P_t})^{\rho-1}}{(1-\lambda_t)(\frac{D_t}{P_t})^{\rho} + \lambda_t(\frac{B_t^h}{P_t})^{\rho}} = u_c(C_t)\frac{i_t - i_t^d}{1+i_t} \tag{12}$$

$$\frac{\alpha\lambda_t(\frac{B_t^h}{P_t})^{\rho-1}}{(1-\lambda_t)(\frac{D_t}{P_t})^{\rho} + \lambda_t(\frac{B_t^h}{P_t})^{\rho}} = u_c(C_t)\frac{i_t - i_t^b}{1+i_t} \tag{13}$$

Equation (12) reflects the valuation of inside money, or deposits, by households. I assume households rely on deposits to make transactions and are therefore willing to accept an interest rate on deposits i_t^d that is below the intertemporal rate. The opportunity cost of money $i_t - i_t^d$ 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. Equation (13) reflects that, for households, bonds might serve the same purpose as deposits.

D.2 Banks

The representative bank in this economy exists because households cannot access central bank's reserves directly. The bank therefore originates liquid deposits by either holding assets or by holding reserves at the central bank. Specifically, I assume banks take deposits, on which they promise to pay a riskless nominal return i_t^d one period later and hold other assets (such as loans) on which they earn a nominal interest rate of i_t. They also choose a quantity of reserves M_t^d to hold at the central bank on which they will receive a nominal yield of i_t^m. The bank takes all these interest rates as given.

Banks face liquidity shocks because their debt is inside money used by households for transactions. Reserves are more useful for handling liquidity shocks than other assets: if they are sufficiently scarce, banks are willing to pay a higher price. This is the demand curve that many central banks exploited before 2008: they targeted a positive spread between the interbank rate and the reserve rate (which was zero in the case of the US), and elastically supplied reserves to achieve that spread.

The bank will consume real resources $\theta(\frac{\zeta_t D_t^s}{M_t^d})$, where $\theta_D > 0$, $\theta_M < 0$ and $\theta_D = \theta_M = 0$ for $M_t^d \geq \overline{M}_t$. This specification resembles the banks' demand for reserves in the model of Poole (1968) and Afonso et al. (2020). This tries to capture that liquidity costs are increasing in deposits (higher chance of unexpected withdrawals and greater precautionary liquidity demand), decreasing in reserves (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 reserve requirements and above their precautionary demand level, $\overline{M}_t$. ζ_t is the average propensity to use deposits for payments, which I assume to be a negative function of overall endowment Y_t.

Lastly, banks can issue deposits if they have sufficient collateral to back them:

$$D_t^s \leq M_t^d + \rho_L L_t^s \qquad \rho_L < 1 \tag{14}$$

The parameter $\rho_L < 1$ captures the fact that reserves are better collateral than other assets. Similar to Piazzesi et al. (2021) and Benigno and Benigno (2021), this constraint can be interpreted as a capital requirement. From the households' Euler equation, deposits provide a convenience yield whenever the supply of real balances is finite. It follows that, from the perspective of the bank, deposits represent a source of funding that is strictly cheaper than equity, which must earn the illiquid rate i_t. Without a leverage constraint, it would be optimal to fund the bank entirely with deposits. The leverage constraint will thus bind in equilibrium.

Banks' cash flow is given by:

$$\begin{aligned}&\Omega_t = D_t^s - D_{t-1}^s(1 + i_{t-1}^d) + M_{t-1}^d(1 + i_{t-1}^m) - M_t^d + \\ &L_{t-1}^s(1 + i_{t-1}) - L_t^s - \theta(M_t^d, D_t^s; \zeta_t)\end{aligned} \tag{15}$$

Banks' cash flows are discounted at the households' illiquid rate, i_t. Let γ_t be the multiplier on the leverage constraint. The maximization of the present value of cash flows is given by:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \left\{ \left(\frac{1}{1+i_t} \right)^t \Omega_t + \gamma_t (M_t^d + \rho_L L_t^s - D_t^s) \right\} \tag{16}$$

The first order conditions with respect to reserves and deposits are, thus:

$$\frac{i_t - i_t^m}{1+i_t} = \gamma_t - \theta_{Mt} \tag{17}$$

$$\frac{i_t - i_t^d}{1+i_t} = \gamma_t + \theta_{Dt} \tag{18}$$

The left-hand side of Equation (17) shows the marginal cost of an extra reserve: the forgone interest with respect to other assets. The right-hand side is the marginal benefit: a looser collateral constraint and a lower liquidity cost (as $\theta_{Mt} < 0$). The left-hand side of Equation (18) is the marginal benefit of an extra deposit: cheaper funding due to the special demand by households. The right-hand side shows the marginal cost: a tighter collateral constraint and a larger liquidity cost ($\theta_{Dt} > 0$).

By subtracting equation (18) from equation (17) I obtain the spread between the rate on deposits and the rate on reserves:

$$\frac{i_t^d - i_t^m}{1+i_t} = \begin{cases} -\theta_{mt} - \theta_{dt} & \text{if } M_t^d < \overline{M}_t, \\ 0 & \text{otherwise} \end{cases} \tag{19}$$

where recall that $\theta_{mt} \leq 0$. For $M_t^d < \overline{M}_t$, equation (19) delivers a one-to-one relationship between the supply of reserves and the policy rate. 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 $M_t^d \geq \overline{M}_t$, then $\theta_D = \theta_M = 0$ and the policy rate equals the interest on paid on reserves.

The choice of i_t^d as the central bank's policy rate can be justified as follows. In reality, the Fed sets the federal funds rate, which is the rate at which banks trade reserve balances intraday among themselves. The federal funds rate can, therefore, be seen as the rate at which banks can obtain liquid funding whenever needed. Although in the model there is no interbank market, 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. Introducing a more formal interbank market and a more realistic federal funds rate would complicate the model without improving the exposition of the underlying mechanisms.

D.3 Government and Central Bank

I introduce a government in the simplest way possible. Every period, it raises taxes from the household and supplies new debt issuance. Its flow budget constraint is given by:

$$B_t^s = (1 + i_{t-1}^b) B_{t-1}^s - T_t - T_t^{cb} \tag{20}$$

where B_t^s is total debt issued, 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 reserves to the banking system. Its budget constraint is:

$$M_t^s + (1 + i_{t-1}^b) B_{t-1}^{cb} = B_t^{cb} + M_{t-1}^s (1 + i_{t-1}^m) - T_t^{cb} \tag{21}$$

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 (government and central bank) is:

$$B_t^h + M_t^s = (1 + i_{t-1}^b) B_{t-1}^h + M_{t-1}^s (1 + i_{t-1}^m) - T_t \tag{22}$$

I assume that fiscal policy is set in real terms. A shown in Canzoneri and Diba (2005), this is necessary to achieve local determinacy in nominal variables. The real supply of bonds, B_t^s/P_t, will follow an exogenous path. Taxes/transfers adjust so the budget constraint holds every period. This is a simplification, as it is likely that the maturity structure of government debt is not exogenous to the stance of monetary policy. However, this simple modeling will deliver sharp intuitions and contrasts with the existing literature.

D.4 Monetary policy implementation

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

$$i_t^{d*} = \psi \left(\frac{P_t}{P_t^*} \right)^{\psi_\pi} e^{\xi_t} \tag{23}$$

where P_t^* represents a target path for the price level and ξ_t is an exogenous random shock. This policy rule does not consider the possibility of a zero lower bound, as the calibration for New Zealand in the period before 2020 will not involve such episodes.

I further assume that:

$$i_t^m \geq 0 \tag{24}$$

which can be rationalized by the existence of cash, in addition to deposits and T-bills: in this case, the interest paid on reserves and deposits will not fall below the rate paid by cash, which is zero. I consider the economy to be in the cashless limit and refrain from explicitly introducing cash into the model.

The central bank has three instruments at its disposal: the policy rate, i_t^d, the interest it pays on its reserves, i_t^m, and the supply of reserves to banks, M_t^s. Under a corridor or scarce-reserve system ($M_t^s < \overline{M}_t$), given an interest on reserves (zero in the case of the US before 2008), there is only one level of the supply of reserves that achieves the target for i_t^d, through equation (19). As a result, the supply of reserves is not an independent tool.

I model the implementation of the floor system as the central bank setting $M_t^s > \overline{M}_t$ at all times. Therefore, by equation (19), $i_t^d = i_t^m$ and every period teh central bank sets the interest on reserves, i_t^m. The supply of reserves becomes an independent tool as long as $M_t^s > \overline{M}_t$. To keep things simple, I assume the supply of reserves M_t^s follows an exogenous random path that never falls below $\overline{M}_t$. This exogenous shock tries to represent random demand by households due to unexpected liquidity needs (change in precautionary demand or unexpected liquidity withdrawals by households). Besides this shock, the central bank does not endogenously set M_t^s.

This is a simple representation of 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. 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*** *(...).The Committee continues to view changes in the target range for the federal funds rate as its* ***primary means*** *of adjusting the stance of monetary policy*" (emphasis is mine).

Under this system, monetary policy outside the ZLB no longer works through the supply of reserves by banks. Since banks face no liquidity cost, adjustments in the policy rate i_t^m only work through the households' cost of liquidity. Imagine there is an increase in liquidity demand (for instance, an exogenous increase in α in the model). The convenience yield of deposits will increase (left hand side of (12)). The central bank will respond by easing monetary policy: lowering i_t^m. This increases the household's cost of liquidity, $i_t - i_t^m$, on the right-hand side. Intuitively, since monetary policy no longer works through the supply of reserves, it can only respond through the household's cost of liquidity: facing an increase in demand for liquidity (bigger α), it increases the cost of it for households, $i_t - i_t^m$.

It is helpful to consider what would happen were the central bank not to react. The increase in the convenience yield of deposits would result instead in an increase in the intertemporal rate, i_t. This would also increase the household's cost of liquidity, $i_t - i_t^m$, but at the same time it would result in a drop in the price level, leading the central bank to miss its target.

It might seem counterintuitive that the central bank eases monetary policy by actually *increasing* the cost of liquidity. To understand this, notice the distinction between the household's cost of liquidity and the bank's cost of liquidity. Under a corridor system, monetary policy works mainly through the bank's cost of liquidity: an easing of monetary policy *reduces* the cost of liquidity of banks, thus increasing the *supply* of deposits. This is how we usually understand monetary policy: central banks reduce the policy rate to reduce the cost of liquidity in the economy. In a floor system, on the other hand, banks are satiated and face no cost of liquidity. Monetary policy works only through the household's cost of liquidity, which affects the *demand* for deposits, not their supply. To respond to an increase in demand the central bank can only cool it off by *increasing* the household's cost of liquidity. This in addition explains the negative sign of the coefficient on the interest on reserves in the regressions using New Zealand data.

To sum up, the main differences with respect to Nagel (2016)'s is that in his model the central banks sets the supply of reserves endogenously, and that determines one-for-one the supply of deposits and the monetary policy rate, which corresponds to the intertemporal rate, i_t. In my model, the supply of reserves is exogenous (and so is the supply of deposits) and the central bank endogenously sets the interest paid on them, which in addition carries a premium over the intertemporal rate. This are, at the end, the key differences between a corridor and a floor system.

Definition: An equilibrium in this economy are prices $\{i_t, i_t^b, i_t^m, A_t, P_t, \gamma_t\}$ and policy rules $\{C_t, D_t, B_t^h, D_t^s, B_t^s\}$ such that:

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

I solve the model using the global nonlinear method in Cao et al. (2020).

D.5 Calibration

The model is calibrated with data for New Zealand at quarterly frequency, using the sample 2006:III to 2021:III. Panel A of Table 3 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 3, 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 the sample period. I complement this with two quantities: government debt and banking deposits. I define a supply of government debt to GDP of 0.42 (OECD data, General Government debt) and for deposits I set reserves to GDP at 0.12 and other assets to GDP at 1.4. The ratio of reserves to GDP is obtained from the RBNZ and the supply of other assets matches domestic credit by the banking sector from OECD statistics.

The calibration exercise gives a discount factor of 0.989, which is somewhat lower than usual. However, this difference accounts for the illiquidity of the intertemporal rate in the model. The

Table 3: Parameters (externally calibrated)

	Description	Value	Source
γ	Risk aversion	1.5	Standard
ρ_L	Collateral value of other assets	0.8	
ψ_π	CB's response function	1.5	Standard
β	Discount factor	0.989	
α	Liq. preference	0.0012	
λ	T-bill preference	0.4656	
ψ	CB's response function	1.0084	
P^*	Price level target	1.9727	

Notes:

liquidity preference in the household's utility function, α, takes the value of 0.0012, and the relative usefulness of government debt, λ, is equal to 0.4659. This implies that deposits are only slightly more liquid than T-bills.

Table 4 shows how the model matches the targets for prices (quantities are exogenous in the model and are trivially matched). Last row computes the liquidity premium on government debt.

Table 4: Targets (annualized values)

Variable	Description	Data	Model
i_t	Illiquid rate	4.44%	4.36%
i_t^b	Debt yield	3.25%	2.96%
i_t^m	Interest on reserves (OCR)	3.34%	3.44%
$i_t - i_t^b$	Liquidity premium	1.19%	1.40%

Notes: