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Abstract

We study the recent Australian experience with yield curve control (YCC) of government bonds as perhaps the best evidence of how this policy might work in other developed economies. We interpret the evidence with a simple model in which YCC affects prices of both government and other bonds via "broad" transmission channels, but only government bond prices through "narrow" liquidity channels. YCC seemingly worked well in 2020 while the market expected short rates to stay at zero for long. But as the global recovery and inflation gained momentum in 2021, liftoff expectations moved up, the Reserve Bank of Australia purchased most of the outstanding amount of the targeted government bond, and its yield dislocated from other financial market instruments. The model and empirical evidence point to narrow transmission channels playing more prominent roles than broad channels considered in prior studies of quantitative easing (QE), such as portfolio balance effects and signaling about short term rates. We argue that asset-specific narrow channels may be primary transmission mechanisms of quantity-based QE policies as well.

Key words: monetary policy, yield curve control, quantitative easing

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1 Introduction

With short-term interest rates at the effective lower bound during both the Great Recession and the COVID-19 Recession, central banks around the world adopted policies of quantitative easing (QE), buying large quantities of government bonds, or other similar assets, to further ease financial conditions. QE policies can be divided into those that buy a fixed quantity of bonds and those that target, or cap, a particular yield, collectively known as yield curve control (YCC) policies. Since the mid-1980s, conventional monetary policy in most economies transitioned from targeting monetary (or reserve) aggregates to short-term interest rates. Instead, nearly all QE programs to-date have specified fixed quantities of purchases. An exception to this practice is the policy experiment by the Reserve Bank of Australia (RBA), which, between March 2020 and November 2021, targeted the yield on three-year Australian government bonds (AGBs). Measuring the effects of quantity-based QE outside the initial announcement windows has been an elusive task, but the transparency of explicit yield targets and maturities in YCC provide direct yardsticks to evaluate QE policies.

We study the effects of YCC by fitting smoothed yield curves to AGBs and other fixed income assets that are close substitutes, and fitting an affine term structure model to decompose yields into expectations and term premium components. We find that YCC can achieve targets on the selected security, but the effects of YCC are otherwise narrow with limited spillovers on prices of other financial instruments, and even AGBs with maturities only slightly longer than the AGBs targeted by YCC. Liquidity effects dominate broader preferred-habitat and portfolio-balance channels (Vayanos and Vila, 2021), or signaling effects about the future path of short-term rates (Bauer and Rudebusch, 2014). Collectively, these findings suggest that QE policies ease financial conditions but in a much narrower sense than previously thought (Bernanke, 2012, for example).

The Australian YCC experiment is not the first of its kind. Starting in 1942, in an effort to lower the cost of financing war efforts, the Federal Reserve capped interest rates on Treasury securities at $\frac{3}{8}$ percent for bills, a cap that was subsequently raised to 1 percent in 1947, and at $2\frac{1}{2}$ percent for the longest term Treasury bonds (Toma, 1992). In modern times, the Bank of Japan adopted a YCC policy in 2016, pegging yields on ten-year Japanese Government Bonds around zero. The idea of targeting a price has been considered by economists (Bernanke, 2002) and was noted in the minutes of the June 2020 FOMC meeting, but it has not been adopted in the U.S. since the Treasury accord of 1951. The Japanese experience is of limited relevance to the U.S., since Japan is so intractably stuck at the zero lower bound. For most other economies, the Australian YCC experiment is the most pertinent application in modern times.

Under YCC, the central bank targets one or more points on the government bond yield curve by pledging to buy enough securities to keep the rate at the target. We consider a simple multi-asset model in the spirit of Vayanos and Vila (2021) to interpret the empirical evidence.

We show that YCC shares much of the same features as QE. Both policies affect directly targeted yields, as well as other yields, via a portfolio balance channel, a signaling channel, and an asset-specific liquidity channel. The portfolio balance and signaling channels are "broad" channels and have similar effects on comparable fixed income assets other than those targeted. In contrast, the asset-specific liquidity effect is narrow to the targeted type of asset, or indeed very narrow to the specific targeted security with essentially no spillovers to other maturities or assets. In YCC, the central bank also gives up control of the size of its balance sheet in order to peg rates.

The early experience with YCC appeared to be favorable. The yield on the targeted April 2023 government security fell nearly 25 basis points following the (unexpected) policy announcement on March 19, 2020. Essentially all risk-free Australian interest rates at maturities out to a few years were pushed down close to zero, suggesting that YCC may have reinforced forward guidance via a signalling channel (Bauer and Rudebusch, 2014) and/or put downward pressure on term premia via portfolio balance – both broad channels. While the RBA bought large amounts of the targeted security in March and April 2020, it then largely stopped and the YCC targeted was achieved without needing actual purchases. This is much as the Federal Reserve was historically able to announce a target for the funds rate and achieve it with little in the way of open market operations (Friedman and Kuttner, 2010). In some ways, this experience also resembled the experience of the BOJ with YCC as it achieved its yield target on the 10-year yield with only limited purchases. Yet, the RBA implemented forward guidance policy as well around the same time, noting that it did not expect to increase the cash rate until inflation moved within the 2-3 percent band, which they did not expect to reach before at least 3 years.

However, a narrow liquidity channel of YCC operated already in 2020, as evidenced by a 20 basis point reduction in the spread between AGBs and other comparable fixed-income instruments such as overnight indexed swaps or Australian government bonds issued by states and territories. As the global recovery gained momentum in 2021 and market expectations for liftoff of policy interest rates were moved forward, the limited spillovers of YCC on other yields became much more evident. The RBA purchased substantial quantities of the April 2024 bond—then the target bond—in order to achieve the target and ended up buying the majority of the outstanding security. A kink developed in February 2021 in the AGB yield curve at the April 2024 maturity. Moreover, the AGB yield curve became disconnected from other short-term interest rates, notably the overnight indexed swap (OIS) curve and even state government bond yield curves. We estimate the yield response of AGB yields to YCC purchase operations, and also find that the "flow effects" of YCC were narrow with a sizeable effect on the specific CUSIP but little spillover on other AGBs, OIS expectations or term premia.

The signaling channel of quantitative easing suggests that these policies can successfully reinforce forward guidance. But an affine term structure model indicates that the YCC tar-

get became inconsistent with policy expectations in 2021, suggesting that the effect is limited in practice when the stated commitment differs substantially from what market expectations would otherwise be, which is, exactly when such a reinforcing commitment could otherwise be most valuable. In March 2020, the RBA provided forward guidance that it would not raise the cash rate target before inflation and employment moved towards its goals, which in November 2020, the RBA stated that it did not expect to achieve before at least three years. Despite this guidance and the accompanying YCC target, once inflation rose, policy expectations moved up.

A high-frequency sensitivity analysis of OIS rates to news under YCC in Australia versus New Zealand, where no YCC policies were implemented, also shows that once YCC guidance diverged from the expected market path of the cash rate in 2021 it ceased to impact OIS rates in Australia.

The yield on the Apr-24 AGB jumped after higher than expected inflation data on October 27, 2021, the RBA declined to intervene, formally discontinued the YCC target on November 2, 2021 and softened its longstanding forward guidance that conditions for an increase in the cash rate were unlikely to be met before 2024. It is important to emphasize that the forward guidance given by the RBA was quite clear and did not imply that liftoff from the effective lower bound was imminent. Australia experienced much less inflation than the U.S. For the year ending December 2021, headline (core) CPI rose by 3.5 (2.9) percent over the previous 12 months, which is only slightly above the range targeted by the RBA. As late as November 2021, Governor Lowe commented at a press conference that *"I still struggle with the scenario in which rates need to be raised next year. Things would have to turn out very, very differently than what we currently expect."* Thus, the circumstances were ones where YCC had the potential to reinforce forward guidance, but did not seem to do so.

The Australian experience is informative about how QE works more generally. When a central bank purchases a fixed quantity of assets, we have to assess what happens to the price of that asset and then the price of close substitutes.[1] Event-study evidence suggests that central bank asset purchases have large effects on asset prices (Gagnon et al., 2011; Vissing-Jorgensen and Krishnamurthy, 2011), but at the same time, the event-study only identifies the impact effect while long-run effects may be smaller (Wright, 2012; Hanson et al., 2021; Greenlaw et al., 2018). But when the central bank targets a price, there is no ambiguity about the impact on the price of the asset being bought. The question simply becomes whether the price impact is very narrow (applying only to the asset whose price is fixed) or broader. Before the recovery gained momentum, all short-term interest rates in Australia were close to zero and there is no real way of parsing the relative importance of a weak economy, forward guidance, or YCC. It is indeed possible that YCC played a role at this point. But we find that as the global economic

[1] We take the view that QE works through asset prices not through the volume of reserves *per se* (Bernanke, 2009).

recovery took hold, the price of the bond being targeted became disconnected from the rest of the fixed-income universe. This points to a rather narrow channel for QE more generally. In the paper we distinguish between broad (duration and signaling), narrow (asset class specific) and super-narrow (CUSIP) channels. Our labels are different from those used in the recent work of Krishnamurthy (2022). He only labels policies that affect current of expected future short rates as "broad" and all other unconventional policies, including duration and term premium effects, are "narrow". We, instead, classify duration and signaling effects as broad because prior studies (Vayanos and Vila, 2021; Bauer and Rudebusch, 2014) and our model suggest that they transmit to other long-duration assets and not just government bonds subject to central bank operations. Broad and narrow channels of QE that we discuss fall within the demand system asset pricing approach of Koijen and Yogo (2019) but imply different degrees of substitutability across assets. Narrow channels of QE have been pointed out in other recent studies. In the U.S., Di Maggio et al. (2020) show that purchases of mortgage backed securities by the Fed had the biggest macroeconomic impact because these alone directly affected the borrowing costs of homeowners. Consistent with this finding, Vissing-Jorgensen and Krishnamurthy (2011) and Boyarchenko et al. (2019) find that Fed purchases of agency MBS had a disproportionate effect on agency MBS and, even more strongly, current coupon MBS that were directly targeted. For the U.K., Joyce et al. (2020) show that the Bank of England's QE program targeting Gilts widened spreads of Gilts to OIS. For the Euro area, Altavilla et al. (2014) find that the ECB's Outright Monetary Transaction announcements lowered peripheral spreads but left core European yields unaffected. Lastly, our findings that actual purchase operations affected prices of AGBs are consistent with findings of D'Amico and King (2013) of "flow effects" of Fed asset purchases and also consistent with studies on the impact of primary market issuance in Treasury auctions on yields (see, for example, Duffie, 2010; Lou et al., 2013; Droste et al., 2021).

The plan for the remainder of this paper is as follows. In section 2, we provide background on monetary policy in Australia and describe the timeline of monetary policy events in more detail. Section 3 describes a simple model for interpreting the Australian experience with yield curve control. In section 4, we present data sources, fit yield curves and an affine term structure model to AGBs. Section 5 contains our main empirical evidence on the effects of YCC. Section 6 concludes.

2 Monetary policy in Australia

The monetary policy decision-making body of the RBA is the Reserve Bank Board, which is composed of the Governor, Deputy Governor and seven other members. The Reserve Bank Board sets targets for interest rates to achieve the objectives set out in the Reserve Bank Act of 1959: the stability of the currency, the maintenance of full employment and the economic

prosperity and welfare of the people of Australia. Since the early 1990s, these objectives have found practical expression in a target for the medium-term average of consumer price inflation of 2–3%.

The Board meets eleven times per year, on the first Tuesday of the month except in January. Monetary policy decisions are communicated publicly at 2:30 pm on the day of each Board meeting. The Board also communicates to the public via other means: the minutes of the monetary policy meetings published two weeks after each meeting, four yearly Statements on Monetary Policy, bi-annual testimonies of the Governor before the House of Representatives and monetary policy speeches by the Governor and Deputy Governor.

In recent decades, the Reserve Bank has set monetary policy by targeting the cash rate, which is an inter-bank overnight rate. In Australia, most deposits and loans have variable or short-term fixed rates, so there is a high pass through of changes in these overnight rates to deposit and lending rates. In contrast to the experience in the U.S. and Euro area, the cash rate in Australia remained well above the zero-lower bound during the Global Financial Crisis. It has, however, drifted lower in recent years, reaching 1.5% in June 2019 and 0.75% in February 2020.

As the COVID-19 pandemic took hold around the globe in February 2020, and against a backdrop of rapidly deteriorating economic conditions, the Reserve Bank Board put in place a comprehensive set of easing policies, summarized in Table 1. In March 2020, the Board lowered the cash rate to 0.25% and announced new, and unprecedented, "unconventional" monetary policy easing measures as the cash-rate effectively hit the zero lower bound for the first time.

The Reserve Bank implemented a yield curve control policy (YCC) by announcing in March 2020 that it would stand ready to purchase Australian government securities (AGBs) in the secondary market via long-dated open market operations (OMOs) to target a yield of 0.25%, which was set to to equate the target for the cash rate. The targeted maturity was the closest to three years: the Apr-23 issue until October 29, 2020 and the Apr-24 thereafter. On 3 November 2020, the Board announced that it had lowered both the cash rate and YCC targets to 0.1 percent. In April 2021, the RBA announced that it would decide whether, or not, to roll the target to the next maturity of November 2024. At their July meeting, they decided not to do so and, instead, continued to apply the target to the Apr-24 bond. By fixing the target at a particular maturity calendar date, the RBA seemingly constructed an exit strategy from YCC. But on November 2, the RBA abandoned the strategy after that the targeted bond yield rose well above the target yield in the second half of October.

YCC policies were paired with forward guidance about the future path of the cash rate. In March 2020, the Board first stated in its post-meeting media release that it would not raise the cash rate target until progress was made towards full employment and it was confident that inflation would be sustainably within the 2–3 per cent target band. This forward guidance was further strengthened in the November 2020 media release, which stated that given its projection

Table 1: Timeline of monetary policy actions taken by the RBA between 2020 and 2021. This Table summarizes the timeline of major monetary policy decisions by the Reserve Bank of Australia (RBA). Except for events on October 20, 2020 and October 27, 2021, sources are statements by the Governor on monetary policy decisions, which are released after meetings of the Reserve Bank Board, which is the monetary policy decision-making body.

Date	**Action**
March 3, 2020	Cash rate cut to 0.5%
March 19, 2020	Cash rate cut to 0.25% YCC introduced: target of 0.25% on Apr-23 AGB Forward guidance: "The Board will not increase the cash rate target until progress is being made towards full employment and it is confident that inflation will be sustainably within the 2–3 per cent target band." Term funding facility for banks for 3-years at 0.25% Exchange settlement (ES) balance set at 0.1% Daily repo operations; AGB and semi purchases to improve market liquidity
October 20, 2020	YCC target bond rolls from Apr-23 to Apr-24 AGB
November 3, 2020	Cash rate cut to 0.1% QE program introduced: A$100bn through April 2021 targeting 5-10y AGBs and Semis YCC target reduced to 0.1% Forward guidance: Board is not expecting to increase the cash rate for at least three years.
February 2, 2021	QE program expanded to A$150bn; purchases until Nov 2021 with rate of A$5bn per week
July 6, 2021	YCC target bond Apr-24 AGB retained QE tapering at A$4bn per week after September at least through mid-Nov 2021
September 7, 2021	QE at A$4bn per week until mid February 2022
October 27, 2021	YCC effectively abandoned: RBA declined to intervene following spike in target bond yield
November 2, 2021	YCC officially abandoned Forward guidance: [RBA] will not increase the cash rate until actual inflation is sustainably within the [...] target range. [...] is likely to take some time. [...] Board is prepared to be patient

for the path of employment and inflation, the Board did not expect to increase the cash rate for at least three years – that is, until 2023. This time commitment was removed in November 2021, when the post-meeting media release dropped a reference to the three year horizon and instead stated that it would be "patient" and that it would take some time for inflation to return sustainably to its target range.

The Reserve Bank Board also purchased bonds for reasons other than implementing the YCC target. These purchases included both AGBs and Australian state and territory government securities, commonly referred to as the semi-government securities or "semis," . Starting in March 2020, purchases were aimed at improving deteriorating market liquidity and reduce market dislocations and included both AGBs and semis. In November 2020, the Reserve Bank Board announced a more traditional QE program targeted towards AGBs and semis in the 5-10 year sector, which was formally known as the Bond Purchase Program. The formal announcement was foreshadowed by a speech of Governor Lowe's on October 16, 2020. The QE program was aimed at easing financial conditions by lowering longer-term interest rates over and above the indirect effect of YCC in the 3-year sector. This round of QE also specifically targeted a given program amount, which was first set to be A$100 billion to be spent through April 2021. The program size was then increased to A$150 billion with a target end date of November 2021, implying weekly purchases of about A$5 billion. At the July 6 meeting, the Board announced the tapering of QE by communicating that it had decided to reduce purchases to A$4 billion per week starting in September, and that this pace would have been maintained through November At the September meeting the Board announced its intention to maintain the A$4 billion pace through February 2022.[2]

The rest of the paper focuses on the effects of purchases by the RBA of AGBs, which were targeted by YCC. Figures 1, 2 and 3 summarize key features of RBA purchases of AGB securities under long-dated OMOs and Bond Purchase Program. Long-dated OMOs (referred to as YCC purchases thereafter) included purchases to implement the YCC target and to support liquidity in the AGB market in the spring of 2020. Purchases under the Bond Purchase Program (in short QE purchases thereafter) were used to implement QE.

The orange bars in Figure 1 show the distribution of daily YCC purchases between March 2020 and October 2021. The blue bars in the Figure are daily QE purchases starting on the day after the QE announcement on November 3, 2020. The Figures reveal key differences between purchases under the two programs. First, YCC purchases were irregular in size and ranged from zero on most days to A$5 billion on March 20, 2020, which is the day after the program was announced. In contrast, QE daily purchases were frequent and essentially al-

[2]The Reserve Bank also announced in March 2020 that it would provide a Term Funding Facility (TFF) for the banking system to lower funding costs for banks. Under the drawdown period for the TFF, banks had access to new 3-year funding at 0.25%, which was an interest rate substantially below their funding costs. The TFF closed to new drawdowns in June 2021.

Figure 1: RBA purchases under long-dated OMOs and bond purchase programs. This figure plots daily purchases of Australian government bonds (AGBs) under the RBA's long-dated open market operations (OMOs), which include both YCC and market functioning purchases, and under the bond purchase program (quantitative easing, or QE). Daily purchases under each program typically included multiple CUSIPs. The orange line represents cumulative purchases under OMOs.

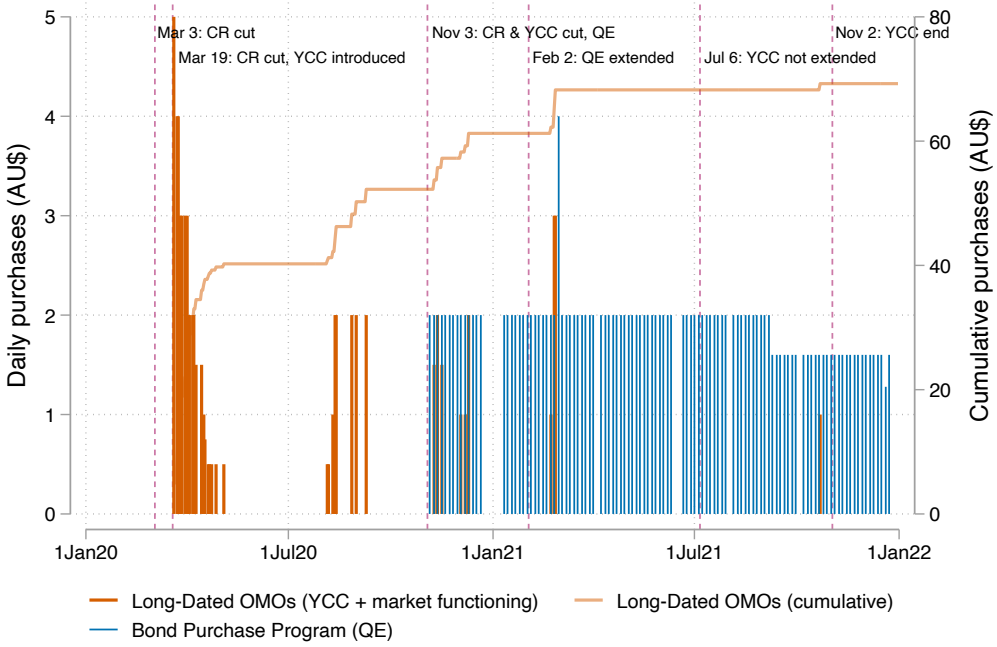


Figure 2: Cumulative RBA purchases under long-dated OMOs and bond purchase programs. This figure plots cumulative purchases of Australian government bonds (AGBs) under the RBA's long-dated open market operations (OMOs), which include both YCC and liquidity purchases, and under the bond purchase program (quantitative easing, or QE). The left panel shows purchases in A$ and the right panel as a share of total amount outstanding.

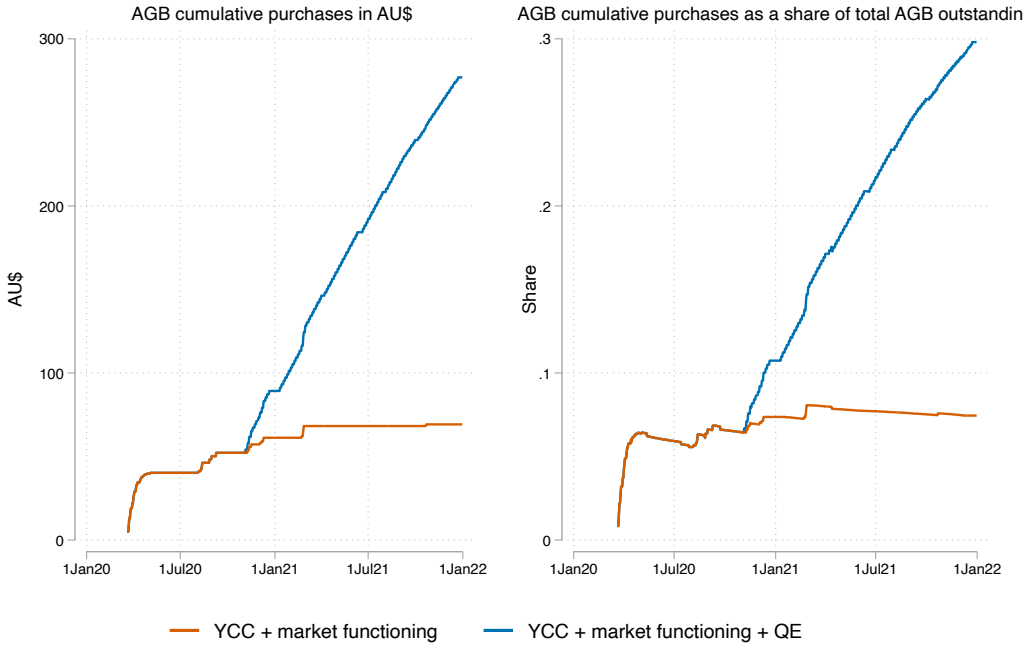
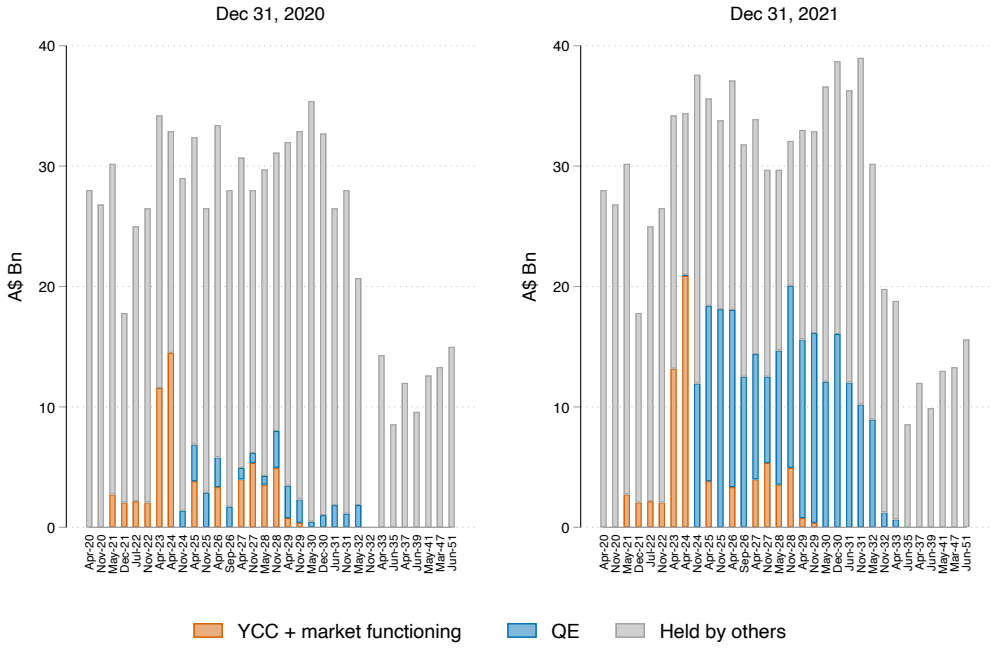


Figure 3: Distribution of cumulative RBA purchases against amounts held by holders. This figure plots cumulative purchases of Australian government bonds (AGBs) under the RBA's long-dated open market operations (OMOs), which include both YCC and liquidity purchases, and under the bond purchase program (quantitative easing, or QE) as of Dec 31, 2020 and Dec 31, 2021, and those held by other investors.



ways of equal total amount. YCC purchases were also front-loaded in the spring of 2020 as indicated by the cumulative purchase (orange) line in the chart. By November 2021, when the program ended, YCC purchases cumulated to about A$70 billion, but only A$10 billion were purchased in 2021. Total YCC purchases accounted for about 8% of total AGBs outstanding by the end of 2021 (Figure 2, right panel). In contrast, QE purchases were much larger at about A$200 billion and accounted for about 22% of total AGBs outstanding. Purchases under the two programs also differed across maturities. As shown in Figure 3, YCC were largely concentrated in shorter-dated maturities, with large purchases in the Apr-23 and Apr-24 issues that accounted for the vast majority of outstanding amounts both as of December 2020 and 2021. QE purchases had longer weighted average maturity and also accounted for large fractions of total AGB outstanding by the end of 2021.

3 Model

We consider a simple model in the spirit of Vayanos and Vila (2021) and Greenwood et al. (2010) to interpret the empirical evidence in the next Section. We use the model to illustrate the different channels through which YCC affects yields on AGBs targeted by YCC and spillovers on longer-dated AGBs and swaps. We also use the model to illustrate differences between YCC and quantity-based unconventional policies. The key takeaways of the model are that, first, YCC shares much of the same features of quantity-based unconventional purchase programs. YCC affects yields via a portfolio balance channel, a signaling channel, and a security-specific liquidity channel. Second, the portfolio balance and signaling channels are "broad" channels. These broad channels have similar effects across all fixed income securities, either directly targeted or not, with loadings that depend on the security's duration. In contrast, the asset-specific liquidity effect is a narrow channel and is specific to the asset class targeted by YCC. Lastly, when the YCC policy is inconsistent with the path of short-term rates or yields on other comparable-maturity assets, YCC has very narrow effects on the targeted AGB with no spillovers to other assets. This "super-narrow" channel, which was prevalent during much of 2021, is not shared with quantity-based policies more in general.

There are four dates: 0, 1, 2 and 3. Short-term interest rates are exogenous and determined by monetary policy through an infinitely elastic storage technology. The short-term rate from 0 to 1, denoted as r_1, is known at time 0. Short-term rates from 1 to 2, denoted as r_2, and from 2 to 3, denoted as r_3, are unknown at time 0, have means μ_i and variances σ_i^2 for $i = 2, 3$, and are independent of each other. In addition, default free two- and three-period bonds $B_{(2)}$ and $B_{(3)}$ exist that pay one unit of wealth at times 2 and 3, and trade at time 0 with prices of $P^{B_{(2)}}$ and $P^{B_{(3)}}$, respectively. In contrast to the short-term rate technology, the supply of these bonds is fixed, their prices are determined endogenously and reflect unconventional policies. Given

date 0 prices, yields on the bond are $Y^{B_{(i)}} \equiv \left(P^{B_{(i)}}\right)^{-i} - 1$ for maturities $i = 2, 3$. We primarily study the effects of unconventional policies on the 2-period bond. We also include the 3-period bond in the model to study cross-maturity spillovers. To understand spillovers on other assets, the model also features two- and three-period swaps $S_{(2)}$ and $S_{(3)}$ that pay one unit of wealth at times 2 and 3 and trade at time 0 with prices of $P^{S_{(2)}}$ and $P^{S_{(3)}}$ respectively, which are also determined endogenously.

Payoffs of bonds and swaps with same maturities are identical but their market price can differ reflecting their relative supply, and the fact that investors face other non-pecuniary costs to taking positions in these assets. These costs include liquidity and transaction costs, as well as balance sheet costs, resulting from regulation, or leverage constraints. In the U.S., for example, since the Great Financial Crisis, regulatory reforms to boost macro-financial stability impose constraints on dealers' balance sheet capacity (Duffie, 2018). The supplemental leverage ratio (SLR) introduced with the Basel III regulatory framework constraints leverage for banks—especially for globally systemically important banks —irrespective of risk-weighting for both on-balance-sheet assets, and off-balance-sheet exposures, such as swaps. Other limitations on proprietary trading (such as the Volker rule) and the liquidity coverage ratio (LCR) similarly increases the cost of holding positions in fixed income assets, even if default-free.

The central bank can affect $P^{B_{(2)}}$ via unconventional monetary policy by purchasing the two-period bond (or selling) $B_{(2)}$, in quantity $C^{B_{(2)}}$. We assume that the central bank does not transact in the swap $S_{(2)}$. We define YCC as a program that sets the yield on the 2-period bond $Y^{B_{(2)}}$ to be equal to a target Y^*.

There are four agents: preferred-habitat investors, arbitrageurs, the government and the central bank. Preferred-habitat investors demand at time 0 a quantity $H^{(i)}$ of the i-period assets for $i = 2, 3$. We assume that $H^{(i)}$ is all invested in $B_{(i)}$ if $Y^{S_{(2)}} - Y^{B_{(2)}} \leq \kappa$; otherwise $H^{(i)}$ is all invested in $S_{(i)}$. Thus the preferred-habitat investors are inelastic across maturity, but their demands have some elasticity within maturity consistent with the downward sloping demand curves of Vayanos and Vila (2021).[3]

The government issues a dollar quantity of bonds $Q^{B_{(i)}}$ for $i = 2, 3$, and the swap $S_{(i)}$ for $i = 2, 3$ is in zero-net supply. This is without loss of generality because to solve the arbitrageur's optimization we only need to keep track of the time-0 excess supply net of preferred-habitat quantities demanded. Let $q^{B_{(i)}} = Q^{B_{(i)}} - H^{(i)} \times \mathbb{I}(Y^{S_{(2)}} - Y^{B_{(2)}} \leq \kappa)$ and $q^{S_{(i)}} = -H^{(i)} \times \mathbb{I}(Y^{S_{(2)}} - Y^{B_{(2)}} > \kappa)$ be the residual supplies to arbitrageurs net of the preferred-habitat demands. After taking into account the central bank's unconventional policy, arbitrageurs hold a total $q^{B_{(2)}} - C^{B_{(2)}}$ of bonds $B_{(2)}$. We assume that this quantity cannot be negative because the central bank does not allow shorting. This is consistent with experience in Australia as the RBA limited the extent to which investors could borrow, and thus short, securities from its portfolio. If

[3]The threshold-like formulation is immaterial but yields equilibrium conditions in closed form.

$C^{B_{(2)}} = q^{B_{(2)}}$, then the central bank buys the full amount not wanted by the preferred habitat investors and pays a price corresponding to Y^*. On the other hand, the arbitrageurs' holdings of the swap can be either positive or negative, and match the position of the preferred habitat investors because they are in zero net supply.

As in Vayanos and Vila (2021), arbitrageurs are risk-averse and have limited risk bearing capacity. We depart from their specification in also assuming that arbitrageurs face additional asset-specific non-pecuniary costs to investing. Arbitrageurs finance their positions by borrowing short term. They have risk tolerance γ and non-pecuniary marginal costs θ_B and θ_S to taking positions $a^{B_{(i)}}$ and $a^{S_{(i)}}$. Arbitrageurs start with zero wealth, $w_0 = 0$, and choose $a^{S_{(i)}}$ and $a^{B_{(i)}}$ to maximize mean-variance preferences of expected wealth at time 2, w_2, net of balance sheet and transaction costs.

Arbitrageurs sell the three-period bonds and swaps in the open market in period 2. The price is set exogenously to equate its no-arbitrage value. Because r_3 is known in period 2 and $B_{(3)}$ and $S_{(3)}$ mature at 3, under no-arbitrage, the period 2 price is equal to the discounted value or, up to first order, to $(1 - r_3)$. The objective function of the arbitrageurs is:

$$U\left(a^{B_{(i)}}, a^{S_{(i)}}\right) = E[w_2] - \frac{1}{2\gamma} Var[w_2] - \frac{\theta_B}{2}\left(\sum_i a^{B_{(i)}}\right)^2 - \frac{\theta_S}{2}\left(\sum_i a^{S_{(i)}}\right)^2 \tag{1}$$

where second period wealth is:

$$\begin{aligned} w_2 = &\left(\frac{a^{B_{(2)}}}{P^{B_{(2)}}} + \frac{a^{S_{(2)}}}{P^{S_{(2)}}}\right) + \left(\frac{a^{B_{(3)}}}{P^{B_{(3)}}} + \frac{a^{S_{(3)}}}{P^{S_{(3)}}}\right)(1 - r_3) + \\ &- V(1 + r_1)(1 + r_2). \end{aligned} \tag{2}$$

and $V = \sum_{i=2,3}\left(a^{B_{(i)}} + a^{S_{(i)}}\right)$. The first row in (2) is the return to investing in the two- or three-period asset. The second row shows that arbitrageurs fund the long position V by borrowing in the short-rate technology. To solve the maximization problem note that the expected value of second-period wealth is:

$$E[w_2] = \left(\frac{a^{B_{(2)}}}{P^{B_{(2)}}} + \frac{a^{S_{(2)}}}{P^{S_{(2)}}}\right) + \left(\frac{a^{B_{(3)}}}{P^{B_{(3)}}} + \frac{a^{S_{(3)}}}{P^{S_{(3)}}}\right)(1 - \mu_3) - V(1 + r_1)(1 + \mu_2).$$

and that the variance of second-period wealth is:

$$Var[w_2] = \left(\frac{a^{B_{(3)}}}{P^{B_{(3)}}} + \frac{a^{S_{(3)}}}{P^{S_{(3)}}}\right)^2 \sigma_3^2 + V^2(1 + r_1)^2\sigma_2^2.$$

Assuming an interior solution in which the arbitrageur holds the bond in equilibrium, the first

order conditions with respect to $a^{B_{(i)}}$ are:

$$a^{B_{(2)}}: \frac{1}{P^{B_{(2)}}} - (1+r_1)(1+\mu_2) = \frac{V^2(1+r_1)^2}{\gamma}\sigma_2^2 + \theta_B(a^{B_{(2)}} + a^{B_{(3)}}), \tag{3}$$

$$a^{B_{(3)}}: \frac{1-\mu_3}{P^{B_{(3)}}} - (1+r_1)(1+\mu_2) = V^2(1+r_1)^2\frac{\sigma_2^2}{\gamma} + \theta_B(a^{B_{(2)}} + a^{B_{(3)}}) + \frac{1}{P^{B_{(3)}}}\left(\frac{a^{B_{(3)}}}{P^{B_{(3)}}} + \frac{a^{S_{(3)}}}{P^{S_{(3)}}}\right)\frac{\sigma_3^2}{\gamma}.$$

The first order conditions for $a^{S_{(i)}}$ (formulas omitted) are analogs to (3). The left hand side of the two first order conditions are the expected 2-period excess return over the expected short-term funding cost for $B_{(2)}$ and $B_{(3)}$. The right hand side is the marginal cost to investing in the bond. The first term is the increase in the portfolio exposure to the volatility in r_2 scaled by the size of the portfolio V and the risk aversion parameter γ. This effect shows prominently in Vayanos and Vila (2021) and measures the duration risk to investing in long-term assets. The second term, is the increase in the non-pecuniary cost of holding additional bonds on the balance sheet. The formula for the 3-period bond shows that, in addition, the marginal cost to investing in $B_{(3)}$ includes a term that reflects duration exposure to r_3 When both the habitat and arbitrageur investors hold the bond in equilibrium, the arbitrageur's first order condition holds, and the equilibrium prices are found by substituting the market clearing condition $a^{B_{(i)}} = q^{B_{(i)}} - C^{B_{(i)}}$ and $a^{S_{(i)}} = 0$ in the first order conditions. Then equilibrium yield spreads can be written as:

$$\begin{aligned}
\left(1+Y^{B_{(2)}}\right)^2 - (1+r_1)(1+\mu_2) &= \frac{\hat{V}^2(1+r_1)^2}{\gamma}\sigma_2^2 + \theta_B\hat{V}, \\
\left(1+Y^{B_{(2)}}\right)^2 - \left(1+Y^{S_{(2)}}\right)^2 &= \theta_B\hat{V}, \\
(1-\mu_3)\left(1+Y^{B_{(3)}}\right)^3 - \left(1+Y^{B_{(2)}}\right)^2 &= \left(1+Y^{B_{(3)}}\right)^6\left(q^{B_{(3)}}\right)^2\frac{\sigma_3^2}{\gamma},
\end{aligned} \tag{4}$$

where $\hat{V} = q^{B_{(2)}} - C^{B_{(2)}} + q^{B_{(3)}}$. The first and last expressions are, respectively, the term spreads on the 2- and 3-period bonds. The second expression is the 2-year bond spread to swaps. In the interior equilibrium, the expression for the equilibrium yield spreads in (4) summarizes the effects of central bank purchases $C^{B_{(2)}}$, which we group into broad and narrow channels.

Broad channels of central bank asset purchases: duration and signaling. The broad channels of asset purchases work through a duration and a signaling channel. The duration channel affects the 2-year bond yield spread, $\left(1+Y^{B_{(2)}}\right)^2 - (1+r_1)(1+\mu_2)$, by lowering the quantity of interest rate risk, σ_2^2. This effect is broad across all yields because it lowers the yield on $B_{(2)}$ over the path of short rates, and leaves the swap spread and term spreads unaffected. The signalling channel is an indirect channel of asset purchases that affects expectations about the path of future short-term interest rates (Bauer and Rudebusch, 2014), either by reinforc-

ing a commitment about future monetary policy ("Delphic guidance" as in Campbell et al., 2012) or investors' expectations about the evolution of interest rates given economic conditions ("Odyssean guidance"). The signalling channel is also a broad channel as it affects all yields by changing the expected path μ_2 and term premia by lowering σ_2^2.

Narrow channel of central bank asset purchases: liquidity. Central bank purchases also operate with a narrow channel as they lower the cost of carrying the bond on the balance sheet as measured by θ_B. As shown in (4), the liquidity channel is narrow as it only affects bonds but not swaps. In other words, asset purchases lower the spread of bonds to the expected path of short rates but leave swap yield unaffected.

YCC and the "super-narrow" channel. Under YCC and when the arbitrageur holds $B_{(2)}$ in equilibrium, the central bank sets purchases $C^{B_{(2)}}$ to C^* in order to achieve the target Y^* in:

$$(1+Y^*)^2 - (1+r_1)(1+\mu_2) = \frac{V^{*2}(1+r_1)^2}{\gamma}\sigma_2^2 + \theta_B V.^* \tag{5}$$

where $V^* = q^{B_{(2)}} - C^* + q.^{B_{(3)}}$ The mechanism through which YCC operates is the same as QE, with the exception that C^* is being set endogenously via (5). The lower is Y^* relative to the expected path $(1+r_1)(1+\mu_2)$ the higher is C^*. When Y^* is small relative to $(1+r_1)(1+\mu_2)$ then (5) cannot be satisfied with a positive level of $q^{B_{(2)}}$. In this case the policy becomes "super narrow" in the sense that lowering Y^* no longer affects other assets because $a^{B_{(2)}}$ falls to zero. The effect becomes even stronger when even preferred habitat investors don't hold the asset any longer, which is when $Y^{S_{(2)}} - Y^* > \kappa$.

Bauer and Rudebusch (2014) argue that QE can lead to a strong signaling channel as purchases signal a commitment to keeping short-term interest rates low. YCC provides a clear test for this hypothesis as when such a signaling channel exists, C^* should be small. Instead, when ${Y^*}^2$ is very different from $(1+r_1)(1+\mu_2)$, C^* becomes large and the signaling channel is weak. More generally, the mere fact that Y^* can be significantly lower the expected path of interest rates suggests that the signalling channel from the target Y^* to the expected short-term rate μ_2 will be limited.

Model calibration. Before turning to the empirical evidence, we provide below three calibrations of the models that are useful to interpret the empirical evidence in the next section. The calibrations can result in either interior or corner solutions. Across the three calibrations we set $r_1 = 0$, $Q^{B_{(2)}} = Q^{B_{(3)}} = 1$, $Q^{S_{(2)}} = Q^{S_{(3)}} = 0$, $H^{(2)} = H^{(3)} = 0.5$, $\theta_B = 0.001$, $\theta_S = 0$, $\kappa = 0.002$ and $\gamma = 0.5$ in all cases. In all cases, the central bank also adopts a 10 basis point YCC, or $Y^* = 0.001$, buying whatever amount is needed to enforce this target, which could amount to a corner solution. The three scenarios differ in the choice of the mean μ_i and standard deviation σ_i of r_i for $i = 2, 3$ as shown (in basis points) in Table 2.

Figure 4 shows the resulting asset yields in the three cases. In parameter configuration

Table 2: Mean and standard deviation of short term rates used in the calibrated model. Parameters μ_i and σ_i are the mean and standard deviation of short-term rate r_i in period $i = 2$ and $i = 3$ measured in basis points. Additional parameters used in the model calibration are discussed in Section 3.

Scenario	μ_2	μ_3	σ_2	σ_3
1	10	30	30	50
2	50	100	30	50
3	100	200	50	100

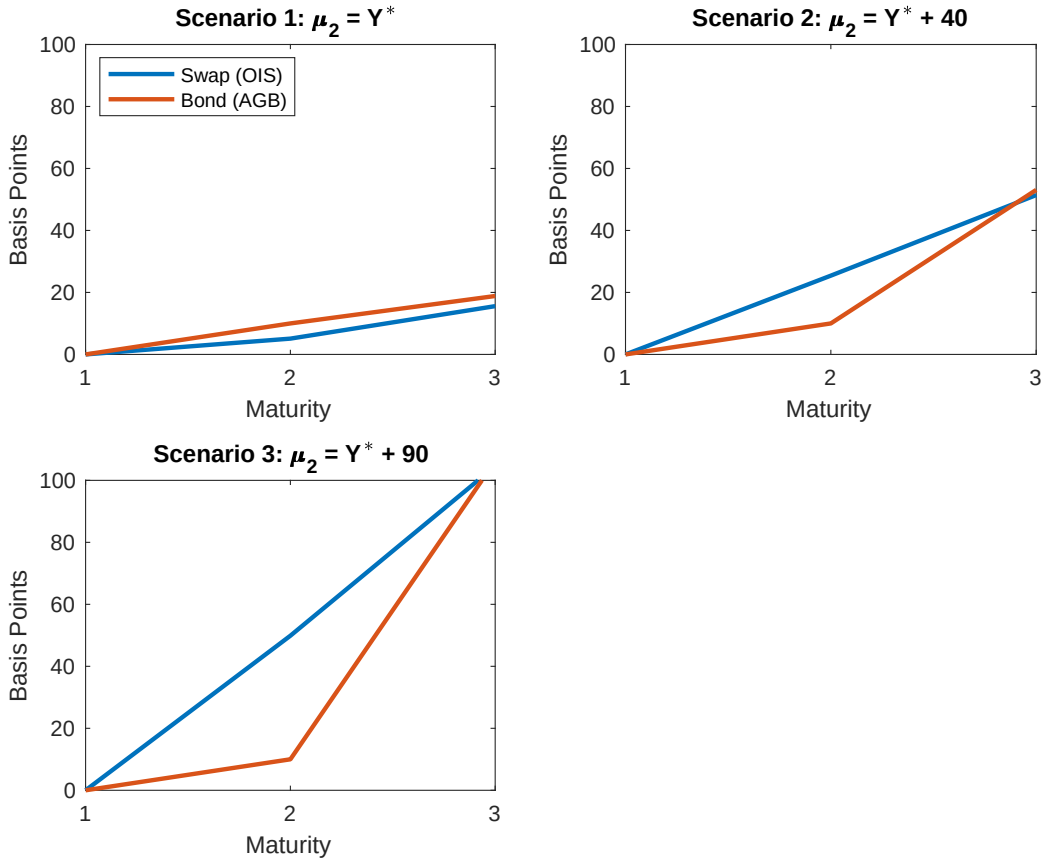
(1), the YCC target ($Y^* = \mu_2 > r_1$) is close to what would be obtained anyway without any central bank purchases, and the central bank only buys 0.014 units of $B_{(2)}$. This is intended to be illustrative of the situation in 2020 in which the YCC target did not really clash with expectations for the path of the cash rate.

In parameter configuration (2), the YCC target is 40 basis points lower than the expected short rate in period 2 (μ_2). The result is that $R^{B_{(2)}}$ is disconnected for the other two-period asset, and also from the three-period bond, giving a kink in the bond yield curve. The central bank holds the YCC target, but only by buying up all of the two-period bond that is not demanded by the preferred-habitat investors, and so they buy 0.5 units of this bond. This is intended to be illustrative of the Australian situation in early 2021.

In parameter configuration (3), the YCC target is even more sharply at odds with short-rate expectations, at 90 basis points below μ_2. Again, the two period bond is disconnected from all other assets, but now the gap between $Y^{B_{(2)}}$ and $Y^{S_{(2)}}$ is so big that the preferred-habitat investors sell all their holdings of $B_{(2)}$ and instead demand the other two-period asset, $S_{(2)}$. The central bank now has to absorb the entire supply of the two-period bond. This is intended to be illustrative of the Australian situation shortly before the collapse of YCC in the Fall of 2021.

Note that it is only because short selling is forbidden that we end up in a corner solution in configurations (2) and (3). If arbitrageurs could take an arbitrarily large short position, then there would still be an interior solution.

Figure 4: Impact of YCC on the swap and government bond yield curves in the calibrated model. This figure plots the bond and swap yield curves implied by the model of Section 3. The YCC target is always set to 10 basis points but the mean (μ_i) and standard deviation (σ_i) of time 2 and 3 short term rates differ across the three calibrations as summarized in Table 2. Additional parameters used in the model calibration are discussed in Section 3.



4 Data, yield curve fitting and an affine term structure model

The model of Section 3 suggests that YCC and QE can affect AGB yields via broad channels (duration and signaling) and narrow channels (liquidity). In the empirical analysis, we attempt to measure the importance of these channels. We extract CUSIP-specific and AGB liquidity effects with yield curve fitting errors and AGB spreads to OIS and state-issued bonds. For broad channels, we decompose OIS yields into a rate expectation and term premium components using an affine term structure model. In the remaining of this Section, we first overview the data and sources and then outline these methods.

4.1 Data

We obtain daily data on quoted yields on all AGBs and state-issued bonds from Bloomberg LP. From Barclays we also obtain daily quotes on overnight index swaps, OIS, at maturities 1, 3 and 6 months, and 1, 2, 3, 5, 10, 20 and 30 years. Overnight indexed swaps are interest rate swap agreements where a fixed rate is swapped against a published index of a floating rates. The OIS is just like other fixed-to-floating rate swaps, except that the floating rate is the overnight cash rate rather than a 3-month rate typically used in plain vanilla interest rate swaps.

We obtain RBA purchases of AGBs from the RBA's release of Monetary Policy Operations (Statistical Table A3) and cash rate targets from the Statistical Table A4. We lastly construct AGB outstanding amounts by CUSIP using AGB issuance data from the Australian Office of Financial Management.

4.2 Yield curve fitting and bootstrapping

In the empirical analysis we use yield curve fitting to assess distortions in AGB prices across maturities and to decompose yield movements into those related to broad changes in AGB yields and CUSIP-specific fitting errors. This fitting error is closely related to the "noise" measure used by Hu et al. (2013) as a proxy for liquidity. We use the yield curve fitting approach of Nelson and Siegel (1987). More detailed discussion can be found in Gürkaynak et al. (2007) but the fitting procedure assumes that instantaneous forward rates n years hence, $f_t(n)$ are characterized by the functional form:

$$f_t^{NS}(n) = \beta_0 + \beta_1 exp\left(-\frac{n}{\tau}\right) + \beta_2 \frac{n}{\tau} exp\left(-\frac{n}{\tau}\right),$$

where NS stands for Nelson-Siegel. With this function, instantaneous forward rates begin at horizon zero at the level $\beta_0 + \beta_1$ and asymptote to β_0. In between, they may have a hump, with a magnitude governed by β_2 and location governed by τ. By integration, the n year zero-

coupon yield is:

$$y_t^{\text{NS}}(n) = \beta_0 + \beta_1 \left[\frac{1 - exp(-\frac{n}{\tau})}{\frac{n}{\tau}} \right] + \beta_2 \left[\frac{1 - exp(-\frac{n}{\tau})}{\frac{n}{\tau}} - exp(-\frac{n}{\tau}) \right]. \tag{6}$$

Given any set of zero-coupon yields, such as OIS or AGB yields[4], we estimate the parameters of the yield curve, $\theta = (\beta_0, \beta_1, \beta_2, \beta_3)'$, on any day by minimizing the sum of squared yield curve fitting errors, solving the problem:

$$\hat{\theta} = \arg\min_{\theta} \Sigma_{i=1}^{k} \left(y_t^{\text{AGB}}(i) - y_t^{\text{NS}}(n(i)) \right)^2, \tag{7}$$

where $y_t^{\text{AGB}}(i)$ is the ith observed yield with maturity $n(i)$ and $y_t^{\text{NS}}(n)$ is given by equation (6). To get good starting points for the numerical optimization, we do a grid search over τ; for any given τ, the solution to equation (7) is available in closed form, as noted by Nelson and Siegel (1987). Where we actually observe zero coupon yields, fitting the curve is just a device for interpolation so as to be able to get a zero coupon yield of *any* maturity, not just the maturities that we happen to observe.

In the empirical analysis, we use the approach to fit a zero-coupon yield curve to AGB coupon-bearing securities, in this case minimizing the sum of the squared differences between observed and predicted yields, where the predicted yields take account of the coupons on the security. The fitting error is then defined as the difference between the coupon-equivalent yield (AGB) and the fitted counterpart (NS).[5]

The Nelson-Siegel yield curve in equation (6) is a smooth function that does not allow for sudden yield discontinuities between neighboring maturities. We assess potential yield curve discontinuities that may arise from YCC by considering an alternative yield curve obtained from "bootstrapping" the forward government bond yield curve under the assumption of constant forward rates between maturity dates. This method results in an unsmoothed yield curve in which forwards follow a step function.[6]

[4]OIS contracts with maturity of one year or less are settled in a single payment at the end, and so we think of these as zero coupon yields. Longer-maturity OIS contracts entail an exchange of fixed for floating every year, and so we think of these OIS rates as implicit par yields. But we convert these into zeros by bootstrapping.

[5]The procedure for obtaining starting values is a bit more complicated, because the parameter estimates are not available in closed form, even conditioning on τ, in the case of coupon securities. To get initial parameter values, we treat each coupon yield as though it were a zero coupon security with maturity equal to the duration of the actual security.

[6]"Unsmoothed" is perhaps misleading terminology because it implies that no smoothing assumption is made. This is incorrect; there is no way of extracting a yield curve from n bond prices without some form of smoothing. But the interpolation in bootstrapping involves a step function that is in some sense the minimum possible degree of smoothing.

4.3 Affine term structure model

To explore the effects of YCC on expectations of future interest rates and on broader term premia, we consider fitting a term structure model to Australian OIS data and decompose these rates into expected future rates and term premia. We fit our model to OIS rates rather than government bond yields because the latter also reflect liquidity changes induced both by YCC and QE as outlined in the model of Section 3.

The model is a standard three factor affine term structure model, subject to the normalization proposed by Joslin et al. (2011). We collect the vector of OIS rates at maturities 1, 3 and 6 months, and 1, 2, 3, 4, 5 and 10 years into a vector Y_t. The model is estimated at the monthly frequency from November 2009 to December 2021. We define a 3x1 state vector X_t that is a linear function of the vector of observed yields such that $X_t = WY_t$, and specifically assume that the state vector consists of the yields at maturities 1 month, 3 years and 10 years. The state vector follows the law of motion:

$$X_t = \mu + \Phi X_{t-1} + \Sigma\varepsilon_t,$$

where ε_t is iid N(0,I),Σ is a lower triangular matrix and the pricing kernel, M_{t+1} is conditionally lognormal such that:

$$M_{t+1} = \exp\left(-r_t - \frac{1}{2}\lambda_t'\lambda_t - \lambda_t'\varepsilon_{t+1}\right),$$

where $\lambda_t = \lambda_0 + \lambda_1 X_t$ and $r_t = \delta_0 + \delta_1' X_t$ is the one month rate, the first element of Y_t.

Joslin et al. (2011) show that the model implies that yields are observationally equivalent to those from a canonical model where under the risk-neutral Q measure:

$$r_t = r_\infty^{(Q)} + i'Z_t,$$
$$Z_t = \Psi^{(Q)} Z_{t-1} + \varepsilon_t,$$

where $\Psi^{(Q)} = diag(\lambda^{(Q)})$ is a 3x3 diagonal matrix, i is a 3x1 vector of ones and Z_t is a rotation of the state vector. The zero coupon yield at maturity n is:

$$y_t(n) = -\frac{A_n}{n} - \frac{B_n^{'}}{n} Z_t, \tag{8}$$

where A_n is a scalar and B_n is a 3x1 vector satisfying the recursions

$$A_{n+1} = -r_\infty^{(Q)} + A_n + \frac{1}{2} B_n' \Sigma\Sigma' B_n,$$
$$B_{n+1} = \Psi^{(Q)\prime} B_n - i,$$

starting from $A_1 = -r_\infty^{(Q)}$ and $A_1 = -i$.

We can thus write

$$Y_t = a_z + b_z Z_t,$$

where a_z and b_z are the coefficients from equation (8) and, recalling that $X_t = WY_t$,

$$X_t = W(a_z + b_z Z_t)$$

and

$$Z_t = (Wb_z)^{-1}(X_t - Wa_z).$$

Thus Z_t is a function of X_t and the model parameters. We assume that the yields at the k other maturities are measured with error such that:

$$Y_t^e = \tilde{a}_z + \tilde{b}_z Z_t + e_t,$$

where $\tilde{a}_z$ and $\tilde{b}_z$ are the coefficients in a_z and b_z omitting the rows that correspond to yields that are measured without error and e_t is iid $N(0,\sigma_e^2 I_k)$ measurement error. Joslin et al. (2011) show that the log-likelihood of this model can be written as:

$$l(\theta) = -\frac{Tk}{2}\log(\sigma_e^2) - \frac{1}{2\sigma_e^2}\Sigma_{t=1}^{T}(Y_t^e - \tilde{a}_z + \tilde{b}_z Z_t)'(Y_t^e - \tilde{a}_z + \tilde{b}_z Z_t)$$
$$-\frac{T-1}{2}\log|\Sigma\Sigma'| - \frac{1}{2}\Sigma_{t=2}^{T}(X_t - \mu - \Phi X_{t-1})'(\Sigma\Sigma')^{-1}(X_t - \mu - \Phi X_{t-1})$$

where θ is the vector of parameters consisting of $r_\infty^{(Q)}$, $\lambda^{(Q)}$, σ_e^2, μ, Φ and the free elements of Σ. Maximization of this log-likelihood is numerically convenient because the regression of X_t on X_{t-1} gives the exact MLE of μ and Φ. This means that the numerical optimization requires finding just 11 parameters in $r_\infty^{(Q)}$, $\lambda^{(Q)}$, σ_e^2 and Σ. Moreover, for the 6 lower triangular elements of Σ, we have starting values from the regression of X_t on X_{t-1}.

Given the assumptions of the model, an absence of arbitrage imposes tight restrictions relating the cross-sectional and time series properties of bond yields. Yield curves are required to be smooth functions of the state vector, and indeed Christensen et al. (2011) show that with a restricted version of the canonical affine term structure model implies that the Nelson-Siegel parameterization holds, up to a small approximation error. We thus think of fitting errors from the Nelson-Siegel or affine term structure models as indications of the price of an individual security being distorted, and thus indicative of the "super-narrow" channel as we discuss in more detail in the results section later.

With this model in hand, we have:

$$E_t(X_{t+h}) = (I + \Phi ... + \Phi^{h-1})\mu + \Phi^h X_t$$

and $E_t(r_{t+h}) = \delta_0 + \delta_1' E_t(X_{t+h})$. Hence we get the path of expected future short-term interest rates. And we can obtain the model-implied fitted yields. Although the model is estimated on monthly data, expected future short rates can be computed each day, as they are all affine functions of observed yields.

5 Empirical Evidence on the effect of YCC

We first present evidence on the impact of YCC, and on the importance of the broad and narrow transmission channels, using time series variation in yields of AGBs, OIS and state-issued bonds (or "semis"). We analyze term spreads and AGB spreads to OIS and semis. We also decompose AGB and OIS yields using the yield curve and affine term structure models presented in the previous Section. We then analyze the high-frequency sensitivity of OIS rates to news under YCC in Australia and compare it to New Zealand, where no YCC policies were implemented, as a control. Lastly, then turn to high-frequency (daily) responses of AGB yields to RBA purchases. We are interested in studying the effects of YCC, but we explicitly consider QE purchases as well, as the two programs were conducted in parallel.

5.1 Time series evidence

Evidence from AGBs and OIS. The March 19, 2020 announcement that the RBA would target the yield on the Apr-23 AGB at 25 basis points came as a surprise. Figure 5 plots yields on four AGB securities: Apr-23 and Apr-24 that were targeted by YCC (red) and the next two maturing issues that were not (Nov-24 and Apr-25, blue lines). The YCC target bond rolled from the Apr-23 to the Apr-24 AGB in October 2020. As shown by the solid orange line in Figure 5 the yield on the Apr-23 bond fell from 48 basis points to 35 basis points on that day, dropping further to the 25 basis point level over subsequent days. In short order essentially all risk-free Australian interest rates at maturities out to a few years were pushed down close to zero. This can be seen in the top panel of Figure 6 that plots the entire term structure of quoted AGB yields (hollow circles) against their duration as well as fitted AGB yields (blue) implied by the estimated Nelson-Siegel curve. The top (bottom) panel of the Figure shows these yield curves on selected days in 2020 (2021).

Taken in isolation this evidence suggests that YCC was very effective at lowering AGB yields, both those targeted as well as yields of maturities further out. As shown in Figure 1, the RBA bought large amounts of 3 year AGBs in March and April 2020 and then largely stopped. AGB yields remained low throughout the summer of 2020. Under one interpretation of the evidence, the 3 year yield target was "credible" and so, for some time after May 2020 the announcement itself was sufficient to accomplish the YCC target without needing actual further purchases. This is much as the Federal Reserve was historically able to announce a target for

the funds rate and achieve it with little in the way of open market operations (Friedman and Kuttner, 2010). In this respect, YCC appeared to be more effective than standard quantity-based QE programs by keeping yields low even without conducting purchase operations. But as noted in Table 1, the RBA implemented YCC on March 19, 2020 along with a portfolio of additional easing measures and, most importantly, lowering the target for the cash rate to 25 basis points and providing forward guidance that "[it] will not increase the cash rate until further progress [was made towards its objectives]," which was reinforced in November 2020 with guidance that "[it did] not expect[...] to increase the cash rate for at least three years." As a result, the AGB yield response does not directly tell us the counterfactual of what would have happened if the RBA had followed every other policy as it did, but leaving out YCC. One interpretation from the model is that the broad channels were at play. YCC purchases lowered the term premia via the duration channel (consistent with Vayanos and Vila, 2021) and YCC reinforced forward guidance via the signaling channel (as in Bauer and Rudebusch, 2014). But from the discussion of the model calibration, it is also clear that the limited purchases of AGBs during 2020 were consistent with a scenario in which the YCC target is equal to market expectations about the path of short term rates (scenario 1). In fact in this scenario, the term premium effect is limited because of the small volume of purchases.

AGB yields continued to seemingly respond to YCC policies in the fall of 2020. First, as the RBA rolled the target bond from the Apr-23 to the Apr-24 AGB issue on October 20, the two yields converged (Figure 5, solid and dashed orange lines). Second, the AGB yields targeted declined to 10 basis points as the YCC (*and* cash rate) target was lowered on November 3. On October 16 Governor Lowe noted that the paucity of purchases under YCC meant that the RBA balance sheet had grown less than in other developed economies. He suggested that the RBA was considering a standard QE program, which was officially announced on November 3. As earlier in 2020, the lower YCC target was achieved in the fall and winter of 2020 with limited purchases.

But as the global recovery gained momentum in early 2021, expectations for liftoff of policy interest rates over the next year rose. This is seen by the jump in the dashed blue line in Figure 7, which corresponds to the expectations hypothesis OIS component of maturity equal to the duration of the targeted bond, as implied by the affine term structure model of Section 4. As this happened, the RBA purchased large quantities of the Apr-24 AGB issue and by late 2021 it owned the vast majority of the balance outstanding as shown in Figures 1 and 3.

Following these purchases, the yield on issues up to the Apr-24 maturity (orange line in Figure 5) remained at the YCC target but those yields became disconnected from other interest rates. First, the Apr-24 yield became disconnected from the duration-matched OIS (Figure 7). The widening of this spread is what the narrow channel predicts (second first order condition in equation 4). This is also consistent with Joyce et al. (2020) who study the effects of the Bank of England Quantitative Easing program on Gilt-OIS spreads and also find evidence that Gilt

Figure 5: Yields on AGBs targeted and not targeted by YCC. This figure shows the yield on AGBs targeted by the RBA's YCC program (Apr-23 and Apr-24) against the closest maturity securities not targeted by the YCC program. The YCC target switched from the Apr-23 to the Apr-24 AGB in October 2020 and is in effect between Mar, 2020 and Nov, 2021.

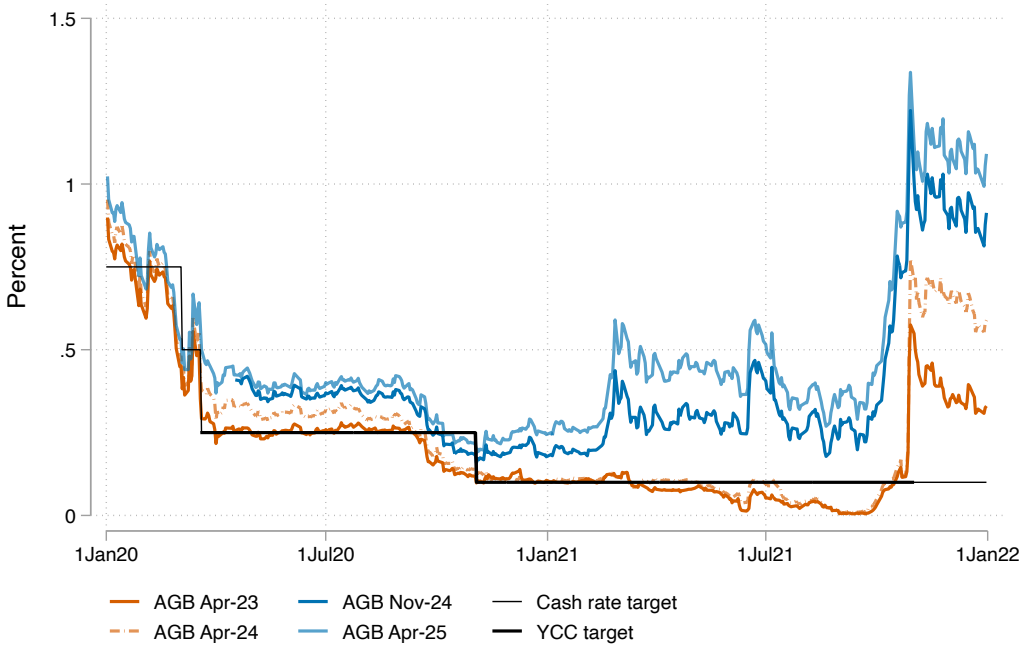
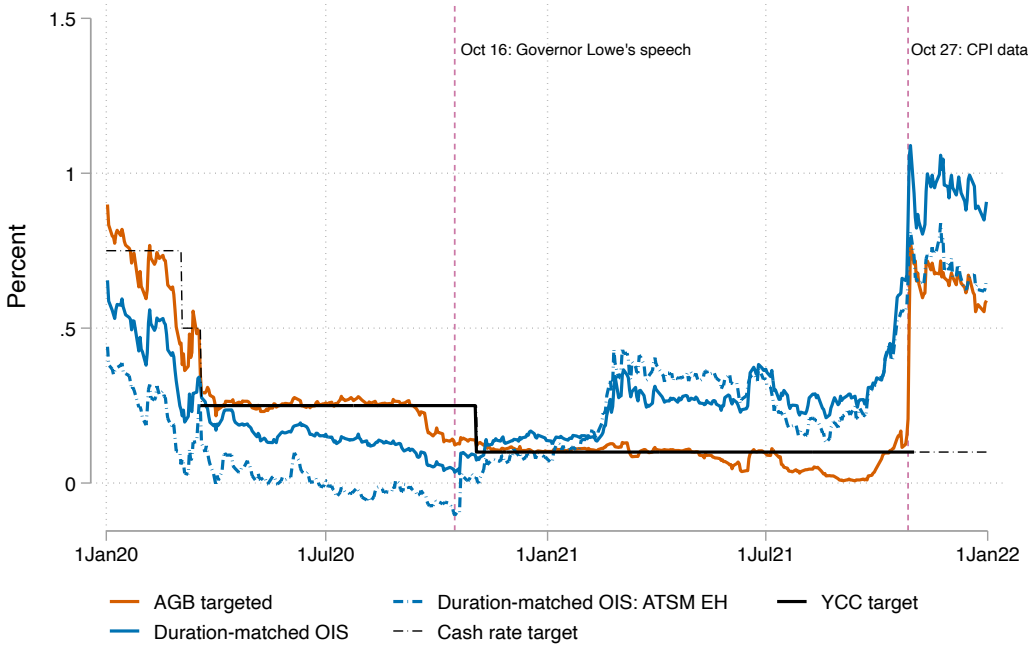


Figure 6: AGB yield curves on selected days. This figure plots yields on AGBs and highlights the securities included in the YCC program (Apr-23, and Apr-24) and the next-maturity security excluded (Nov-24) in the YCC program. The chart also shows a Nelson Siegel curve (details in Section 4) estimated on AGB yields (ZC AGB yield) and on OIS yields (OIS), as well as the YCC target yield level (YCC target) on each date.

Figure 7: Yields on AGBs targeted by YCC and duration-matched OIS. This figure shows the yield on AGBs targeted by the RBA's YCC program (Apr-23 prior to October 2020, and Apr-24 thereafter) against a duration-matched overnight index swap rate (OIS) and the expectations hypothesis component of this rate from the affine term structure model of Section 4.



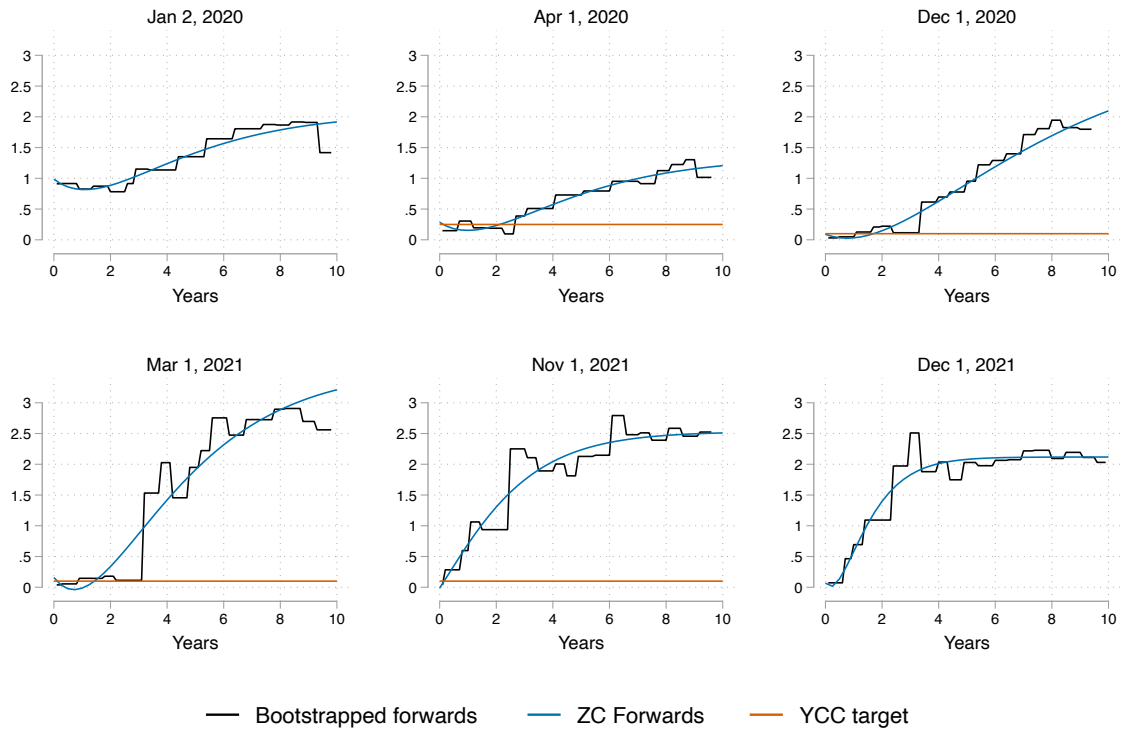
purchases resulted in the widening of spreads. Furthermore, and specific to YCC, the Apr-24 yield also decoupled from AGB yields of slightly longer maturities as shown by the blue line in Figure 5. Issues maturing in Nov-24 and Apr-25, essentially act as a YCC control group. As shown in the bottom left-panel of Figure 6, a kink developed in the government bond yield curve at the Apr-24 maturity as evidenced by the orange circles in the Figure. This kink in the yield curve is highly unusual because it suggests an arbitrage opportunity of shorting the Apr-24 issue, which trades rich, and buying the Nov-25 issue. This anomalous pricing is even more evident when comparing the term structure of bootstrapped unsmoothed forward rates, which are constructed by imposing that forward rates are constant between two adjacent AGB maturities as discussed in Section 4. As seen in the bottom panels of Figure 8, starting in the spring of 2021, a large discontinuity opened up around the 3-year sector, with forward rates jumping about 1.5 percent around the YCC target maturity. This is exactly what the model of Section 3 implies under the "super-narrow" channel when the YCC target is too high relative to the expected path of short-term interest rates. Yields on the targeted AGB become detached from swap rates, a kink develops in the yield curve and the central bank ends up holding much of the outstanding securities.

As seen in Figure 5, on October 27 2021, after that consumer price data were higher-than-expected, the yield on the Apr-24 issue jumped up. The RBA conducted one large operation (Figure 1) but did not intervene in following days as the yield on the Apr-24 issue rose further. The YCC policy was formally discontinued on November 3, 2021.

Even if not the main focus in this paper, it is noteworthy that in October 2020, the duration-matched OIS rate moved up more sharply than it's expectations hypothesis component (compare the solid and dashed blue lines in Figure 7). This happened at the time of Governor Lowe's speech foreshadowing a more conventional QE program. This program ended up being very big, buying A$4 billion per week in AGBs concentrated in the 5 to 10 year maturity range. In October 2020, the term premium component of OIS rates went from being positive to being around zero, and then it went negative early in 2021. This is consistent with the QE program operating to some degree through term premia—a broad channel when purchases are very large. After the collapse of the YCC program, the OIS term premium reverted to being positive, suggesting that this effect was ultimately not very persistent. Finlay et al. (2021) estimated that the QE program lowered longer-term AGB yields about 30 basis points and we return to the persistence of the effects below.

The total purchases of the April-2024 bond from October 2020 to October 2021 were A$13.9 billion. Over this period, the April-2024 averaged about 20 basis points rich to the OIS curve, and it's duration was about 3 years. A back-of-the-envelope calculation would indicate that the RBA had instead bought these securities at the yield implied by the OIS curve, they would have paid about A$83 million less. This could be an understatement of the amount that the RBA "overpaid" because bond yields before March 2020 were typically above OIS rates in

Figure 8: Forward rates on AGBs. This Figure plots the bootstrapped forward AGB yield curve. Yields are bootstrapped under the assumption of a constant forward rate between maturity dates. The figure also includes zero-coupon smoothed forward rates implied by a Nelson Siegel curve estimated on AGBs. Details in Section 4.



Australia, and because the RBA also bought substitute bonds in defense of the target, although they were only slightly rich to the OIS curve. A calculation like this measures the *ex ante* cost of the purchases. The actual *ex post* cost will depend on the comparison of the yield on the purchased securities with any interest that the RBA will have to pay on reserves, for the purpose of management of short rates, up to the point that these securities mature.

While we cannot fully identify the counterfactual of what would have happened if the RBA had omitted the yield curve target, consistent with the prediction of our model the gravitational pull of the AGB yield curve on other short-term interest rates was limited, and this became evident as the expected path of short term rates detached from the the YCC AGB target. The outcome appears more along the lines envisioned of the irrelevance proposition of open-market operations of Eggertsson and Woodford (2003) as the RBA bought up the targeted bond, but achieved little else. As noted earlier, this somewhat resembled the outcome of the Fed's capping interest rates during and immediately after World War 2, although the recent Australian experience involved accumulating almost the entire stock of the targeted asset much faster.

Evidence from state-issued bonds. The narrow channel of YCC (second first order condition in equation 4), suggests that purchases of AGBs should be associated with a widening of AGB spread to other safe fixed income instruments. Figure 7 showed that the Apr-24 yield became disconnected from the duration-matched OIS in 2021. Here we present additional evidence using semi government bonds, or "semis," which are issued by Australian states and territories. Semis have a guarantee from the state government and in some cases a federal guarantee. Semis should thus be quite close substitutes for federal bonds. The comparison between Australian federal and state bonds thus gives an indication of spillovers of YCC policies on highest-quality bonds, for example, spillovers from U.S. Treasury yields onto agency MBS or AAA corporate bond yields.

We fit Nelson-Siegel zero-coupon curves to state bond yields for each state separately using bonds with maturities less than 10 years. Australia has 6 states and 2 territories, but we omit Tasmania and both territories because they have few bonds, leaving us with 5 state yield curves that are all very close to each other. We then take the spread between the Apr-24 federal bond yield and the duration-matched zero coupon yield from each state's yield curve. This is shown as the red lines in the left panel of Figure 9, where the thick line is the average across the 5 state yields. The blue lines repeat the exercise, but for the Apr-26 bond as a control, with the motivation being that Apr-26 is clearly away from the RBA's target maturity. The right panel of Figure 9 takes the spread between the zero-coupon state bond yields for each state separately and the OIS curve at the maturities equal to the durations of the Apr-2024 (red) and April-26 AGBs (blue). We see that semis spreads to AGBs widened sharply in March 2020 because of global flight to quality and that this liquidity event persisted through May 2020. The liquidity episode affected state bonds across maturities, and in fact spreads in the Apr-24 and Apr-26 comoved in this episode (red and blue lines, left panel). While the paper focuses on the effects of RBA purchases on AGBs, both market functioning and QE purchases included semis as well, with 20% of QE purchases being allotted to semis. These purchases seemingly pushed semi spreads to AGBs (left panel) and to OIS (right panel) to low levels in 2020. But as the YCC 3-year target diverged from market expectations for the cash rate starting in 2021, semi spreads on the Apr-24 AGB widened significantly and decoupled from the Apr-26 AGB spread (blue line, left panel) and from OIS rates (red and blue lines, right panel). In conclusion, when YCC became inconsistent with expectations for the cash rate the richness of the target bond did not spill over to state bonds, even though state bonds were also being purchased by the RBA. This evidence is again consistent with the super-narrow channel of the model of Section 3.

5.2 Sensitivity of Australian OIS rate changes to U.S. OIS rate changes

The time series evidence showed that, consistent with the "super-narrow" channel of the model in Section 3, when the YCC is inconsistent with policy expectations, yields on the targeted AGB

Figure 9: Spreads of duration-matched state bond yields over select AGB and OIS rates. The left panel plots the spread of state zero coupon yield curve over the yield on the Apr-24 or the Apr-26 AGB where the duration of the state yield curve is equal to the duration of the corresponding AGB. The thick lines are averages taken over spreads (thin lines) for New South Wales, Victoria, Queensland, Western Australia and South Australia. The right panel plots the spread of each state zero coupon yield curve (thin lines) and their means (thick line) over the corresponding OIS curve at maturity equal to the duration of the Apr-24 federal government bond and Apr-26 AGB.

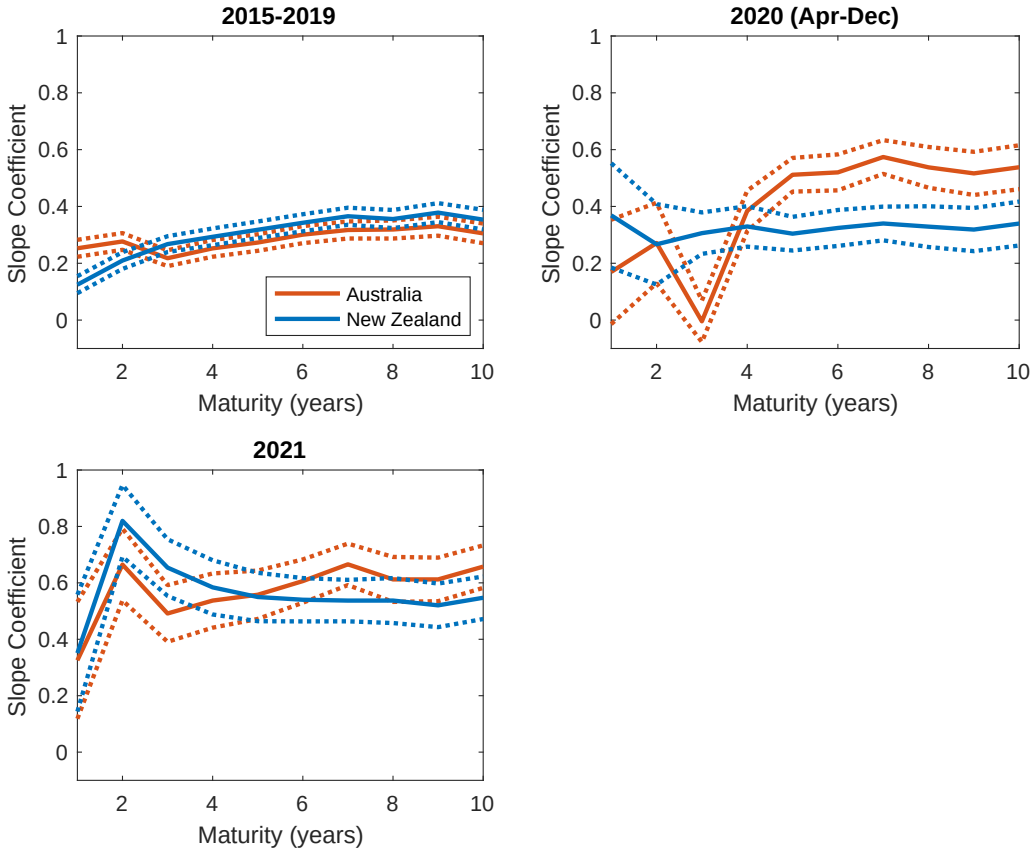
become detached from other rates. The signalling "broad" channel of YCC would, instead, suggest that YCC is a policy commitment that spills over market expectations for the path of short term interest rates.

As another way to address the spillover of YCC onto market expectations for short term rates, here we study how shocks to global interest rates (as measure by U.S. rates) affect OIS rates at high-frequency in Australia and in New Zealand, which serves as a control group. We run regressions of the form:

$$y_{t,k} - y_{t-1,k} = \beta_k (y^{US}_{t,k} - y^{US}_{t-1,k}) + \varepsilon_{t,k} \tag{9}$$

where $y^{AUS}_{t,k}$ is the Australian or New Zealand OIS rate of maturity k years on day t and $y^{US}_{t,k}$ is the corresponding U.S. OIS rate. The coefficient β_k measures the sensitivity of daily changes in Australian or New Zealand OIS rates to their U.S. counterparts. In Figure 10, we report the estimates of β_k for different sample periods along with 68% confidence intervals. New Zealand serves as a control as its economy is highly connected and shares similarities (including COVID

Figure 10: Sensitivity of Australian and New Zealand OIS rate changes to U.S. counterparts. This Figure plots the coefficient estimates from equation (9) (solid lines) along with 68% confidence intervals based on robust standard errors for both countries for selected sample periods.



policies) with Australia, but without the same YCC policy.

In the period from 2015-2019, we see that both Australia and New Zealand exhibited similar sensitivity to U.S. OIS rates. In the period April-December 2020, the sensitivity of Australian OIS rates declined specifically around the 3 year maturity; there was no such pattern for New Zealand. In 2021, both Australian and New Zealand exhibited similar heightened sensitivity to U.S. OIS rates. This is again consistent with the pattern of the RBA having been successful with forward guidance in 2020, and with YCC possibly contributing to this success while the target for YCC and the cash rate were consistent (scenario 1 in the model). But once the YCC guidance diverged from the expected market path of the cash rate then it ceased to have much impact (scenario 3 in the model).

5.3 High frequency effects of purchases and purchase rules

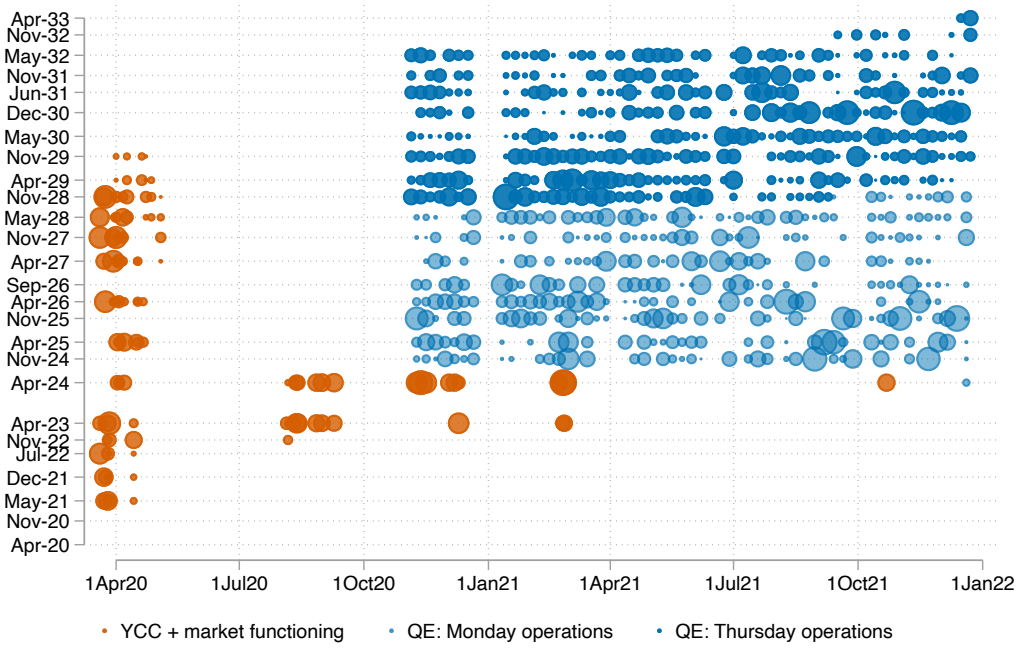
In the model of Section 3, central bank purchases occur when equilibrium prices and yields are determined. In reality, the RBA pre-announced YCC and QE purchases just like other foreign central banks had done during the Great Recession and COVID-19 Recession. Any asset pricing model (including ours) in which forward looking investors price financial asset in terms of future prices and cash flows implies that asset prices respond to credible purchase announcement even if no actual purchase has occurred. In fact, as shown in the time series evidence, AGB yields responded to both YCC and QE announcements, consistent with prior studies on the effects of central bank QE announcements (Gagnon et al., 2011; Vissing-Jorgensen and Krishnamurthy, 2011). But existing studies also show that central bank transactions have a high-frequency impact on price. For example, D'Amico and King (2013) study the security-level effects of Federal Reserve large scale asset purchases and find significant impacts. Others have studied the closely-related impact of primary market issuance in Treasury auctions on yields (see, for example, Duffie, 2010; Lou et al., 2013; Droste et al., 2021), which despite being known well in advance affect secondary market Treasury yields.

In this Section, we study how daily RBA purchase operations affected yields on the AGBs and on OIS. We first analyze how the RBA conducted its daily operations in Australian government bonds to implement YCC and QE policies and then turn to estimates of yields to daily purchases when also taking into account the estimated purchase rules. We find evidence of large flow purchase effects of YCC (and QE). Consistent with the evidence thus far, the effects were narrow to specific AGBs targeted in RBA's purchase operations with little spillover on other AGB maturities, or the market implied path of short-term rates, either as measured as by the OIS or its expectation component from the affine term structure model.

5.3.1 AGB purchase rules

In conjunction with the initial announcements of unconventional policies (Table 1), the RBA released accompanying market announcements with specifics such as the composition, amounts and schedule of AGB purchases. The level of detail differed between YCC and QE operations. YCC policies set price, not quantity, targets and thus market statements indicated the type, but not the amounts, to be purchased. The statements also expressed the RBA's commitment to achieve the announced targets noting that it "stood ready" to conduct purchase operations to ensure that the yield on the 3-year Australian Government bond remained consistent with the Board's target, and to address liquidity or other market dislocations. Market announcements about QE included more specifics. In November 2020, the RBA announced that AGB daily operations would total A$2 billion and that purchases would occur weekly on Mondays and Thursdays. In July 2021, the RBA announced that the amounts would be reduced to A$1.6 billion starting in September 2021 (Figure 1). Purchases of AGBs with residual maturity of 5-7

Figure 11: Distribution of RBA purchases of AGBs by maturity, date and purchase program. This figure shows the distribution of daily purchases of Australian government bonds (AGBs) under the RBA's long-dated open market operations (OMOs), which include both YCC and liquidity purchases, and under the bond purchase program (quantitative easing, or QE). The distribution is shown by maturity (vertical axis), day of purchase (horizontal axis) and program (color). The size of the bubbles are proportional to the purchased amounts.



years would occur on Mondays, and purchases of 7-10 year maturity AGBs would take place on Thursdays. Within those maturity buckets, market statements noted that purchases could reflect relative valuations. Figure 11 shows the distribution of AGB purchases by maturity (vertical axis), day of purchase (horizontal axis) and program (color). The size of the bubbles are proportional to the purchased amounts. A few features stand out. YCC purchases for liquidity and market functioning were concentrated in the spring of 2020 (orange bubbles in the Figure). Instead, all subsequent purchases under the program were specific to the Apr-23 and -24 AGB issues targeted by YCC. Furthermore, YCC purchases were lumpy with no purchases on most days but large purchases on few days. This is in contrast with the distribution of QE purchases, which were very stable as announced in the market statements. Figure 11 shows that Monday operations focused on 5 to 7 maturities (light blue), while Thursday operations included 7 to 10 year maturities (dark blue). But while the weekly patterns, total amount and maturity buckets of QE purchases were highly predictable, the exact CUSIP composition of the purchases wasn't as we discuss next.

Table 3: Summary statistics for variables included in Tables 4, 5, 6 and 7. The panel is formed as the universe of 32 AGBs and 504 trading dates between January 1, 2020 and December 31, 2021. Yields and spreads are expressed in basis points. "AGB" is the AGB yield, OIS is a matched-maturity OIS rate, NS is the AGB yield fitted from the Nelson-Siegel curve, OIS^{EH} is the expectation OIS component from the affine term structure model. Purchased amounts are in A$. Purchases either include all same-day purchases ("TOT") or split purchases on a given AGB ("CUSIP") and others ("OTHER") under the YCC-liquidity program ("YCC") and QE program ("QE"). "QE-THU" ("QE-MON") is an indicator for AGB maturities purchased on Thursday (Monday) QE operations and corresponding weekday. "YCC" is an indicator for the Apr-23 and Apr-24 issue and "OTHER" for non "YCC" issues. "YCC-GAP" is the difference between the AGB yield and the YCC target rate. "QE-CBUY" and "YCC-CBUY" are cumulative CUSIP purchases under the QE and YCC programs. "OUST" is the total CUSIP outstanding. "MAT" is years to maturity.

	Mean	Std. Dev.	Max	Min
ΔAGB	0.0	4.6	32.8	-37.2
ΔOIS	0.1	3.5	20.9	-32.5
Δ(AGB - NS)	0.0	1.6	23.4	-35.4
Δ(NS − OIS)	-0.0	2.8	55.0	-26.4
ΔOIS^{EH}	0.0	1.7	13.4	-18.3
$\Delta(OIS\text{-}OIS^{EH})$	0.0	2.6	18.7	-29.0
YCC-TOT	0.1	0.5	5.0	0.0
QE-TOT	0.4	0.8	4.0	0.0
YCC-CUSIP	0.0	0.1	2.3	0.0
QE-CUSIP	0.0	0.1	1.6	0.0
YCC-OTHER	0.1	0.5	5.0	0.0
QE-OTHER	0.4	0.8	4.0	0.0
QE-THU	0.0	0.2	1.0	0.0
QE-MON	0.0	0.2	1.0	0.0
YCC	0.1	0.2	1.0	0.0
OTHER	0.1	0.3	1.0	0.0
YCC-GAP	0.8	0.7	2.8	-0.3
QE-CBUY	2.3	4.1	18.1	0.0
YCC-CBUY	1.8	3.4	20.9	0.0
OUTST	24.7	8.9	39.0	3.5
MAT	9.1	7.0	30.8	0.0
Observations	14050			

Table 4: AGB purchase rules. This Table reports estimates of equation (10). The dependent variables are purchased amounts (in A$) for a given AGB under the under the YCC-liquidity program ("YCC") and QE program ("QE"). "QE-THU" ("QE-MON") is an indicator for AGB maturities purchased in Thursday (Mon) QE operations. "YCC" is an indicator for the Apr-23 and Apr-24 issue and "OTHER" for non "YCC" issues. "YCC-GAP" is the difference between the AGB yield and the YCC target rate. "MAT" is years to maturity. $(AGB - NS)$ is the Nelson-Siegel yield curve fitting error, a measure of market discount. "QE-CBUY" and "YCC-CBUY" are cumulative CUSIP purchases under the QE and YCC programs. "OUTST" is the total CUSIP outstanding. The "-1" subscript refers to data as of the close of the previous day. The total number of CUSIPs included in each regression is 32. The sample starts in January 1, 2020 and ends on December 31, 2021 for a total of 504 trading dates. CUSIPs are included from the date of issuance to the month prior to expiry. Standard error clustered on each trading date are reported in brackets. Significance: $^{*}p < 0.1$, $^{**}\ p < 0.05$, $^{***}p < 0.01$.

	(1) QE-CUSIP	(2) QE-CUSIP	(3) QE-CUSIP	(4) YCC-CUSIP	(5) YCC-CUSIP
QE-THU	0.147***	-0.043			
	[0.016]	[0.085]			
QE-THU×(AGB - NS)$_{-1}$	0.013***	0.011***	0.006**		
	[0.003]	[0.003]	[0.003]		
QE-MON	0.224***	0.036			
	[0.018]	[0.088]			
QE-MON×(AGB - NS)$_{-1}$	-0.003	-0.004	0.000		
	[0.003]	[0.003]	[0.003]		
QE-MONorTHU×QE-CBUY$_{-1}$		-0.004**	-0.004**		
		[0.002]	[0.002]		
QE-MONorTHU×OUTST$_{-1}$		0.007**	0.007**		
		[0.003]	[0.003]		
YCC				0.040***	0.042***
				[0.009]	[0.009]
YCC×YCC-GAP$_{-1}$				0.195**	0.195**
				[0.085]	[0.085]
OTHER×(AGB - NS)$_{-1}$				0.001***	0.001**
				[0.000]	[0.001]
OTHER×YCC-CBUY$_{-1}$					-0.011*
					[0.005]
OTHER×OUTST$_{-1}$					0.003***
					[0.001]
OTHER×MAT					-0.003***
					[0.001]
Const.	0.000**	0.000**	0.016	0.002***	-0.000
	[0.000]	[0.000]	[0.083]	[0.001]	[0.000]
N	14055	14055	974	14055	14055
Adj. R^2	0	0	0	0	0
Conditional on:			QE-MON = 1 QE-THU = 1		

We estimate the parameters of the bond purchase rules using specifications of the form:

$$\text{BUY}_{it} = \alpha + \beta' X_{it} + \varepsilon_{it} \tag{10}$$

where BUY_{it} is the volume of purchases of the i^{th} CUSIP on day t and X_{it} is a vector of observable control variables. This is useful not only to understand how daily purchases were conducted but also when we estimate the price effects of purchases below we use the same control variables that determine purchases as additional covariates. Summary statistics of the variables included in the regressions are reported in Table 3. Table 4 summarizes the panel regression estimates for equation (10). The dependent variables are purchases (in A$) under the QE (columns 1-3, "QE-CUSIP") and YCC (columns 4-5, "YCC-CUSIP") programs for each AGB. The total number of CUSIPs included in each regression is 32. The sample starts in January 1, 2020 and ends on December 31, 2021 for a total of 504 trading dates. CUSIPs are included from the date of issuance to the month prior to expiry. Standard errors are clustered by date. The first regression specification for QE purchases includes two variables that indicate whether a bond is included in the maturity bucket and day of operation ("QE-MON" and "QE-THU"). These indicators are also interacted with the yield curve fitting error, which is the difference between the AGB actual yield and the corresponding yield predicted by the Nelson-Siegel curve, $(AGB - NS)_{-1}$, measured as of the previous day close (see Section 4 for the exact construction). When this term is positive, the actual yield is higher than the fitted yield and the AGB security trades at a discount to the fitted value implied by the yield curve. Based on the market announcement discussed above we would expect purchases to be increasing in this term. The fitting error is interacted with the QE dummy variables to reflect the fact that QE purchases occurred in predetermined weekdays and maturity buckets. We consider two dummy variables to determine if the fitting error had a differential role in the two maturity buckets. As shown in column 1, and consistent with what we saw in Figure 11, the two QE indicators are highly statistically significant (p-val<0.01). The fitting error terms are only statistically significant for longer-maturity operations (p-val<0.01). In column 2, we extend the set of controls with past cumulative QE purchases and the stock of total securities outstanding. We again interact these variables with an indicator for either Monday or Thursday operations. The estimated coefficients indicate that purchases increased with the size of the issues and declined the more of these securities had been purchased in past operations (p-val<0.05). Over time these coefficient estimates imply that RBA QE daily operations were dispersed across CUSIPs within each maturity bucket, which is consistent with the resulting distribution of cumulative purchases across CUSIPs as of the end of 2021 (Figure 2, right panel). The set of controls in the regressions explain a significant portion of the pooled variation in QE purchases (adjusted $R^2 \geq 0.35$). But much of this explanatory power reflects the indicator variables –i.e. maturity buckets and weekday of operations were fixed – and not the remaining control variables

– the fitting error, cumulative purchases and amounts outstanding. In fact, while these additional controls remain significant when we condition the sample to observations for which QE-MON and QE-THU are one, the adjusted R^2 drops to 0.01 (column 3). In other words, while weekdays and maturity buckets were fixed, the exact CUSIP composition of each operation remained uncertain. The last two columns of Table 4 characterize purchase rules for the YCC program. We separately analyze purchases to implement the YCC target by conditioning on an indicator variable ("YCC") for the Apr-23 and -24 issues and market functioning purchases, which included all other securities ("OTHER"). For "YCC" purchases, we condition on the the difference between the actual yield and the YCC target ("YCC-GAP") as of the prior close, consistent with the RBA market announcement. We expect this term to be positive, so that when the yield on the Apr-23 and -24 issues is higher than the YCC target purchases are more likely to take place. For the market functioning component we, instead, include the yield curve fitting error for which we would expect a positive sign. The signs of point estimates (column 4) are consistent with the priors both for YCC-GAP (p-val<0.05) and for the yield curve fitting error (p-val<0.01). For securities other than the Apr-23 and -24 issues we also include cumulative past purchases, amounts outstanding and the maturity of the security (column 5). Similar to the QE purchase rules, we find that purchases were smaller with higher prior buys of the same CUSIP and the larger the issued amount. Purchases were also more likely for shorter-dated securities consistent with Figure 11. While many of the explanatory variables are highly significant (columns 4 and 5), these variables only explain a small fraction of the YCC purchase variation (adjusted $R^2 < 0.05$). For example, purchases in the Apr-23 and -24 issues were more likely the larger YCC-GAP term. But aside from the spring of 2020, the actual purchased amounts were infrequent even when the YCC-GAP was positive. We conclude that the market announcements were informative about the actual operations, but with limited information on the exact timing of YCC purchases and the CUSIP composition of QE purchases within each maturity bucket. Below we include these controls as robustness checks of the estimated yield effects.

5.3.2 Yield effect of daily AGB purchases

We estimate the response of AGB yields to YCC and QE purchases and decompose those effects into liquidity and other components to identify whether broad or narrow channels (as discussed in Section 3) were most important. We estimate the coefficients of the panel linear regression:

$$\Delta y_{it} = \alpha + \beta' \text{BUY}_{it} + \varepsilon_{it} \tag{11}$$

where y_{it} is the yield on an AGB with CUSIP i and date t or the duration-matched OIS yield (in basis points), and BUY is a vector containing daily RBA purchases. As with the AGB purchase rule regressions that we just discussed, the panel is formed by 32 securities over trading dates

in 2020/21. We separate purchases (in A$ billions) under the YCC-liquidity ("YCC") and QE program ("QE"). For each AGB maturity and date, the BUY vector in the specifications either include total purchases of all AGBs under the YCC program ("YCC-TOT"), or we split purchases for that specific AGB ("YCC-CUSIP") from those on other securities ("YCC-OTHER"). We also likewise include the corresponding purchases under QE (either "QE-TOT" or both "QE-CUSIP" and "QE-OTHER"). Summary statistics of all variables in the regressions are reported in Table 3. Standard errors are clustered on each trading date to account for correlation in yield changes on a given date.

Table 5 reports coefficients estimates of linear regressions of changes in AGB yields and duration-matched OIS (equation 11). AGB yields and matched OIS rates decline with both total YCC and QE purchases, but the coefficients are not statistically significant when considering total purchased amounts (columns 1 and 2). When we split purchases between those on the CUSIP over which the AGB yield change is defined and those on other CUSIPs, we see that same-CUSIP show large and statistically significant negative effects on the AGB yields (column 3) but not on the matched-maturity OIS (column 4). An A$1 billion purchase under the YCC programs lowers the yield of that specific AGB by 2 basis points (p-val$<$0.01), while purchases under the QE program lower the yield by about half as much (1 basis point, p-val$<$0.01). These effects are quantitatively very large. For example, as shown in right panel of Figure 3, the RBA purchased a cumulative A$20 billions of the Apr 2024 issue via the YCC program. The point estimates suggest that these purchases lowered the yield on the AGB Apr-24 issue about 40 basis points.

Robustness of the estimated yield effects. We next consider the robustness of these estimated effects. First, the large estimated effect of YCC may over-estimate the true long-run effect if the effect is transitory. We assess the extent to which this may be the case using local linear projections (Jordà, 2005) by running the regression:

$$y_{it+h} = \alpha + \beta_h' \text{BUY}_{it} + \Sigma_{k=1}^{6} \gamma_{h,k} y_{it-k} + \Sigma_{k=1}^{6} \lambda_{h,k}' \text{BUY}_{it-k} + \varepsilon_{it}. \tag{12}$$

The estimated coefficients on the purchased amounts across different horizon measure the extent to which the purchase flow effects we discussed may be temporary. The point estimates are shown in Figure 12. The day zero effect is, up to slight specification differences, the same as those shown in Table 5 (column 3) and we find a similar 2 basis point effect from each A$1 billion YCC purchase, and a 1 basis point effect from each such QE purchase. While the coefficients are less precisely estimated when looking at yield changes over multiple days, Figure 12 shows that the effect of YCC purchases is persistent (left panel), while the effect of QE purchases (right panel) appears to dissipate after one trading day.

A second concern is that the point estimates may be driven by few outlier observations.

Table 5: Response of changes in AGB and duration-matched OIS yield to RBA purchases. This table reports the estimated regression coefficients of the linear regression in equation (11). The dependent variable is the basis point change in the AGB yield and the duration-matched OIS yield. The independent variables are RBA purchases (in A$ billions) under the YCC-liquidity program ("YCC") and QE program ("QE"). For each AGB maturity and date, purchases either include all same-day YCC/QE purchases ("TOT") or split purchases on a given AGB ("CUSIP") and others ("OTHER"). The estimated coefficient for the constant term is omitted. Additional controls (point estimates not shown) that are included when noted at the bottom of the Table include all variables from Table 4. Column (10) conditions the sample to AGBs that were included in the QE purchases or were part of the YCC target (Apr-23 and 24 issues). The total number of CUSIPs included in each regression is 32. The sample starts in January 1, 2020 and ends on December 31, 2021 for a total of 504 trading dates. CUSIPs are included from the date of issuance to the month prior to expiry. Standard error clustered on each trading date are reported in brackets. Significance: $^{*}p < 0.1$, $^{**}\ p < 0.05$, $^{***}p < 0.01$.

	(1) ΔAGB	(2) ΔOIS	(3) ΔAGB	(4) ΔOIS	(5) ΔAGB	(6) ΔOIS	(7) ΔAGB	(8) ΔOIS	(9) ΔAGB	(10) ΔAGB
YCC-TOT	-0.8	-0.4			-0.1	0.1				
	[0.8]	[0.6]			[0.6]	[0.4]				
QE-TOT	-0.4	-0.1			-0.4	-0.1				
	[0.3]	[0.2]			[0.3]	[0.2]				
YCC-CUSIP			-2.0***	-0.4			-1.6***	-0.1	-2.0***	-1.8***
			[0.5]	[0.3]			[0.4]	[0.2]	[0.5]	[0.5]
QE-CUSIP			-1.1***	-0.2			-1.1***	-0.2	-1.6***	-1.3***
			[0.3]	[0.3]			[0.3]	[0.3]	[0.5]	[0.3]
YCC-OTHER			-0.8	-0.4			-0.1	0.1	-0.6	-0.0
			[0.8]	[0.6]			[0.6]	[0.4]	[0.8]	[0.7]
QE-OTHER			-0.3	-0.1			-0.4	-0.1	-0.4	-0.4
			[0.3]	[0.2]			[0.3]	[0.2]	[0.3]	[0.3]
N	14050	14050	14050	14050	14025	14025	14025	14025	14050	8208
Excl. Mar 20, 2020?					Y	Y	Y	Y		
Add. controls?									Y	
Conditional on:										YCC or QE CUSIPs

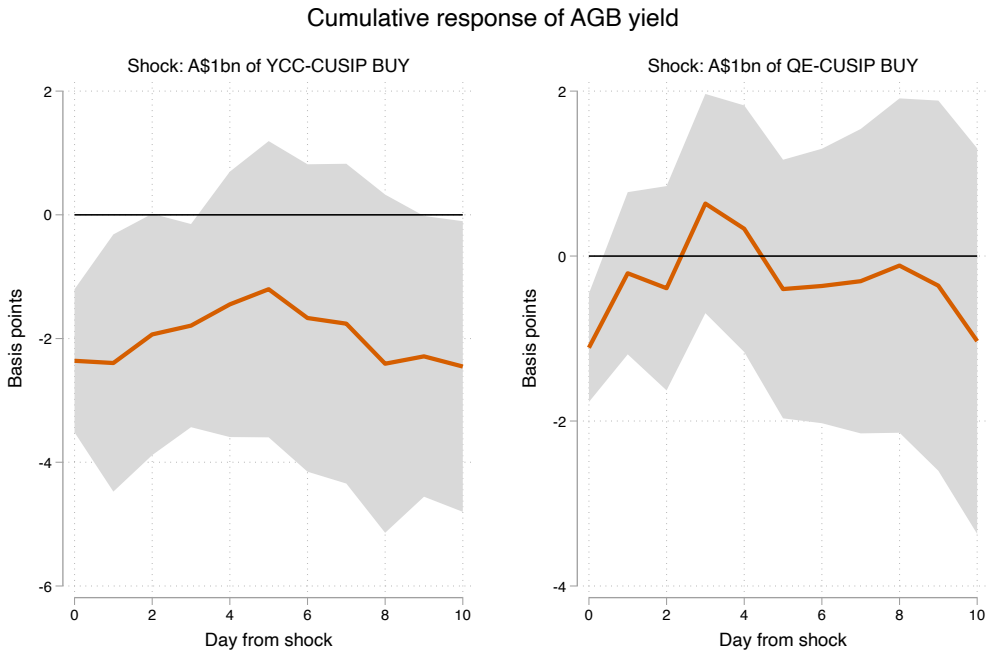
Table 6: Decomposition of changes in AGB yields to RBA purchases. This table reports estimates of the same regression model of Table 5 but decomposing the change in AGB yields (ΔAGB) into a spread to an AGB yield fitted from the Nelson-Siegel curve (ΔNS), a spread to the OIS yield (Δ(NS-OIS)) and the OIS yield itself. The estimated coefficients on AGB add (up to rounding) to those on (AGB - NS), (NS - OIS) and OIS. See notes to Table 5 for additional definitions and sample information. Standard error clustered on each trading date are reported in brackets. Significance: $^{*}p < 0.1$, ** $p < 0.05$, $^{***}p < 0.01$.

	(1) ΔAGB	(2) Δ(AGB - NS)	(3) Δ(NS − OIS)	(4) ΔOIS	(5) ΔAGB	(6) Δ(AGB - NS)	(7) Δ(NS − OIS)	(8) ΔOIS
YCC-CUSIP	-2.0***	-1.4***	-0.2	-0.4	-1.6***	-1.1***	-0.4	-0.1
	[0.5]	[0.4]	[0.4]	[0.3]	[0.4]	[0.2]	[0.4]	[0.2]
QE-CUSIP	-1.1***	-0.4***	-0.6***	-0.2	-1.1***	-0.4***	-0.6***	-0.2
	[0.3]	[0.1]	[0.2]	[0.3]	[0.3]	[0.1]	[0.2]	[0.3]
YCC-OTHER	-0.8	0.4***	-0.7**	-0.4	-0.1	0.3***	-0.5	0.1
	[0.8]	[0.1]	[0.3]	[0.6]	[0.6]	[0.1]	[0.4]	[0.4]
QE-OTHER	-0.3	0.1	-0.3***	-0.1	-0.4	0.1	-0.3***	-0.1
	[0.3]	[0.0]	[0.1]	[0.2]	[0.3]	[0.0]	[0.1]	[0.2]
N	14050	14050	14050	14050	14025	14025	14025	14025
Excl. Mar 20, 2020?					Y	Y	Y	Y

Table 7: Decomposition of changes in AGB duration-matched OIS to RBA purchases. This table reports estimates of the model of Table 5 but decomposing the change in OIS yields (ΔOIS) into an expectation OIS component (ΔOIS^{EH}) estimated from the affine term structure model, and a residual component that includes the estimated term premium and model fitting error. See notes to Table 5 for additional definitions and sample information. Standard error clustered on each trading date are reported in brackets. Significance: $^{*}p < 0.1$, ** $p < 0.05$, $^{***}p < 0.01$.

	(1) ΔOIS	(2) ΔOIS^{EH}	(3) $\Delta(\text{OIS-OIS}^{EH})$	(4) ΔOIS	(5) ΔOIS^{EH}	(6) $\Delta(\text{OIS-OIS}^{EH})$
YCC-CUSIP	-0.4	-0.3	-0.1	-0.1	0.1	-0.3
	[0.3]	[0.5]	[0.4]	[0.2]	[0.4]	[0.4]
QE-CUSIP	-0.2	0.1	-0.3*	-0.2	0.1	-0.3*
	[0.3]	[0.2]	[0.2]	[0.3]	[0.2]	[0.2]
YCC-OTHER	-0.4	-0.2	-0.2	0.1	0.0	0.1
	[0.6]	[0.3]	[0.4]	[0.4]	[0.2]	[0.3]
QE-OTHER	-0.1	0.1	-0.2	-0.1	0.1	-0.2
	[0.2]	[0.1]	[0.2]	[0.2]	[0.1]	[0.2]
N	14050	14050	14050	14025	14025	14025
Excl. Mar 20, 2020?				Y	Y	Y

Figure 12: Local linear projections of AGB yields on shocks to RBA purchases. This Figure plots cumulative local linear projections (impulse reponses) of AGB yields to shocks on same-CUSIP purchases under the YCC-liquidity program ("YCC") and QE program ("QE") as in equation (12). The regression specification includes purchases on other CUSIPs as additional controls and six lags of the dependent and variable and controls. 68% confidence intervals based on standard errors clustered by trading date shown as shaded areas.



As shown in Figure 1, the largest purchases under the YCC program occurred on March 20, 2020, which is also the day after when the YCC program was introduced. As a result, the estimated YCC effect may be overly influenced by this observation if the YCC announcement also had carryover effect on the following day. Columns (5)-(8) of Table 5, repeat the estimation excluding this observation from the sample. As in the baseline specification, total (and other) AGB purchases don't have statistically significant effects on yields. For same-CUSIP purchases, the YCC estimated yield effect declines from 2 to 1.6 basis point suggesting that the March 20, 2020 observation is indeed important but the estimated effects remains large even after excluding the observation. An additional concern on the estimated yield effects is related to the fact that AGB purchases were not randomly assigned. We address these concerns by including in the regression all the explanatory variables of the AGB purchase rules in Table 5. As it can be seen by comparing columns (9) and (3) the estimated effects for YCC are unchanged but we see a stronger effect (1.6 versus 1.1 basis points) of QE purchases. Relatedly, the estimated yield effect of purchases could be the result of differential trends in the yields of targeted securities (YCC and QE) versus others. In the last specification (column 10) we condition the sample to only those AGBs that were included in either operation, and we find very similar point estimates, although the gap between the YCC (-1.8) and QE (-1.3) is again lower than in the baseline specification (column 3, -2 and 1.1 basis points).

Decomposition of the estimated yield effects. We next use the yield curve and affine term structure decomposition to attempt to assess what channels may be important in determining the high frequency response of yield changes on asset purchases. First we note that the response of the duration-matched OIS in Table 5 is negative but never significant, suggesting no signaling channel of flow purchases. Table 6, splits the change in the spread of the AGB yield over the duration-matched OIS into two components: (i) the AGB fitting error, i.e. the difference between the actual AGB yield and the fitted AGB yield from the Nelson Siegel curve[7], and (ii) the spread between the AGB and OIS yield curves. We can see in columns 2 and 3 of the Table that for the YCC-CUSIP buys much of the response is due to the AGB fitting error (row 1), while the effect of QE purchases depends both on the fitting error and the spread between the fitted AGB yield and the OIS. In other words, the YCC program appear to have had a CUSIP-specific effect with little spillover onto other CUSIPs, as indicated by the stability of the yield curve, and consistent with the narrowest possible channel. Instead, the effects of QE purchases were a bit more general. When we exclude the March 20, 2020 observations (columns 5-8) the effects are very similar.

Lastly we use the affine term structure model to decompose the OIS yield change into expectation and term premium components. The results are shown in Table 7. While negative,

[7] This is the difference between the hollow circle and the blue line in Figure 6.

the effect on the OIS yield is never statistically significant. We similarly find the effects on the two components not to be statistically significant and small in magnitude. Recall that as the QE program was announced, term premia did fall (see Figure 7), but here we do not find that the actual purchases had any significant effect on term premia.

In sum, the high frequency evidence also suggests that the flow effects of YCC were narrow with a sizeable effect on the specific CUSIP but little spillover on either OIS expectations, or term premia as indicated by the term premium decomposition.

6 Conclusions

The Australian experience with YCC is an extremely valuable test case for how such policies may work in other developed economies. We conclude that while YCC may have eased financial conditions when investors expected short-term rates to remain low for long in 2020, once the YCC target became inconsistent with the expected path of short-term rates in 2021, the transmission of YCC became "super-narrow," with little or no easing in broader financial conditions. Consistent with our model prediction, the RBA purchased most of the targeted AGB issues with no spillover on either policy expectations (both the OIS and its expectation-hypothesis component), longer-dated AGBs, or close-substitute instruments, such as state-issued bonds.

This outcome of a "super narrow" channel is along the lines of the irrelevance proposition of open-market operations of Eggertsson and Woodford (2003). The RBA bought up the targeted bond, but achieved little else. It also resembles the experience with YCC in the U.S. during World War 2 when the Fed capped bill rates at $\frac{3}{8}$ percent and over time ended up accumulating most of the outstanding bills, reaching 75 percent in 1945 (Garbade, 2020). The Federal Reserve gave up the bill rate cap in 1947, and then began purchasing large quantities of long-term bonds as expectations for short term rates rose. However, the Australian YCC experience involved a much faster accumulation of the targeted asset. YCC might work when it is roughly consistent with market expectations, but does not appear to be successful in holding down the term structure of interest rates other than the targeted security once market participants see the central bank as being likely to begin raising short-term interest rates.

We think that the Australian YCC experiment is informative about quantity-based QE programs as well. The prominent role of narrow liquidity channels suggests that broader channels, such as portfolio-balance and duration effects (Tobin, 1969; Vayanos and Vila, 2021), or signaling about the path of short-term rates (Bauer and Rudebusch, 2014) have little sustained impact. We found that YCC mostly operated through a "super-narrow" channel where only the specific asset being bought was impacted and with no spillovers elsewhere. But we also found some narrow effects on the class of asset being bought beyond that specific security, and

this can ease financial conditions on the targeted assets. But these narrow effects don't spillover onto other financial assets and thus the composition of central bank operations becomes crucial. In the U.S. context, it would imply that Treasury purchases do not have much spillover onto mortgage and corporate rates. Purchases of MBS are likely to have more impact on mortgage rates. And while the Federal Reserve Act does not allow the Fed to buy corporate securities in open market operations, facilities to support financing of corporate bonds, as implemented in 2020, may be effective in lowering yields on this asset class, but again only because this asset class is being targeted. This is consistent with Boyarchenko et al. (2022) who find that "super-narrow" effects operated in 2020 as the Fed corporate bond purchases largely eased financing for facility-eligible issuers.

References

ALTAVILLA, C., D. GIANNONE, AND M. LENZA (2014): "The financial and macroeconomic effects of OMT announcements," *ECB working paper*.

BAUER, M. AND G. D. RUDEBUSCH (2014): "The signaling channel for Federal Reserve bond purchases," *International Journal of Central Banking*, 10, 233–289.

BERNANKE, B. (2002): "Deflation: Making Sure 'It' Doesn't Happen Here," Remarks before the National Economists Club.

——— (2009): "The Crisis and the Policy Response," Stamp Lecture at the London School of Economics.

BERNANKE, B. S. (2012): "Monetary Policy since the Onset of the Crisis," in *Federal Reserve Bank of Kansas City Economic Symposium, Jackson Hole, Wyoming*, vol. 31, 0–24.

BOYARCHENKO, N., A. FUSTER, AND D. O. LUCCA (2019): "Understanding mortgage spreads," *The Review of Financial Studies*, 32, 3799–3850.

BOYARCHENKO, N., A. KOVNER, AND O. SHACHAR (2022): "It's what you say and what you buy: A holistic evaluation of the corporate credit facilities," *Journal of Financial Economics*, 144, 695–731.

CAMPBELL, J. R., C. L. EVANS, J. D. FISHER, A. JUSTINIANO, C. W. CALOMIRIS, AND M. WOODFORD (2012): "Macroeconomic effects of federal reserve forward guidance [with comments and discussion]," *Brookings papers on economic activity*, 1–80.

CHRISTENSEN, J. H., F. X. DIEBOLD, AND G. D. RUDEBUSCH (2011): "The affine arbitrage-free class of Nelson-Siegel term structure models," *Journal of Econometrics*, 164, 4–20.

DI MAGGIO, M., A. KERMANI, AND C. J. PALMER (2020): "How quantitative easing works: Evidence on the refinancing channel," *The Review of Economic Studies*, 87, 1498–1528.

DROSTE, M., Y. GORODNICHENKO, AND W. RAY (2021): "Unbundling quantitative easing: Taking a cue from Treasury auctions," Manuscript, UC Berkeley.

DUFFIE, D. (2010): "Presidential address: Asset price dynamics with slow-moving capital," *The Journal of finance*, 65, 1237–1267.

——— (2018): "Post-crisis bank regulations and financial market liquidity," Banca d'Italia Lecture.

D'AMICO, S. AND T. B. KING (2013): "Flow and stock effects of large-scale Treasury purchases: Evidence on the importance of local supply," *Journal of Financial Economics*, 108, 425–448.

EGGERTSSON, G. B. AND M. WOODFORD (2003): "The zero bound on interest rates and optimal monetary policy," *Brookings Papers on Economic Activity*, 2003, 139–233.

FINLAY, R., D. TITKOV, AND M. XIANG (2021): "An Initial Assessment of the Reserve Bank's Bond Purchase Program," Reserve Bank of Australia Bulletin, June.

FRIEDMAN, B. M. AND K. N. KUTTNER (2010): "Implementation of monetary policy: How do central banks set interest rates?" in *Handbook of monetary economics, Volume 3*, Elsevier.

GAGNON, J., M. RASKIN, J. REMACHE, AND B. SACK (2011): "The Financial Market Effects of the Federal Reserve's Large-scale Asset Purchases," *International Journal of Central Banking*, 7, 3–43.

GARBADE, K. (2020): "Managing the Treasury yield curve in the 1940s," New York Fed Staff Report 913.

GREENLAW, D., J. D. HAMILTON, E. HARRIS, AND K. D. WEST (2018): "A skeptical view of the impact of the Fed's balance sheet," National Bureau of Economic Research Working Paper 24687.

GREENWOOD, R., S. HANSON, AND J. C. STEIN (2010): "A gap-filling theory of corporate debt maturity choice," *The Journal of Finance*, 65, 993–1028.

GÜRKAYNAK, R. S., B. SACK, AND J. H. WRIGHT (2007): "The US Treasury yield curve: 1961 to the present," *Journal of monetary Economics*, 54, 2291–2304.

HANSON, S. G., D. O. LUCCA, AND J. H. WRIGHT (2021): "Rate-amplifying demand and the excess sensitivity of long-term rates," *The Quarterly Journal of Economics*, 136, 1719–1781.

HU, G. X., J. PAN, AND J. WANG (2013): "Noise as information for illiquidity," *The Journal of Finance*, 68, 2341–2382.

JORDÀ, Ò. (2005): "Estimation and inference of impulse responses by local projections," *American Economic Review*, 95, 161–182.

JOSLIN, S., K. SINGLETON, AND H. ZHU (2011): "A new perspective on Gaussian dynamic term structure models," *The Review of Financial Studies*, 24, 926–970.

JOYCE, M. A., A. LASAOSA, I. STEVENS, AND M. TONG (2020): "The financial market impact of quantitative easing in the United Kingdom," *International Journal of Central Banking*, 7, 113–161.

KOIJEN, R. S. AND M. YOGO (2019): "A demand system approach to asset pricing," *Journal of Political Economy*, 127, 1475–1515.

KRISHNAMURTHY, A. (2022): "QE: What have we learned?" *Markus' academy webinar, Princeton Bendheim center (March 24)*.

LOU, D., H. YAN, AND J. ZHANG (2013): "Anticipated and repeated shocks in liquid markets," *The Review of Financial Studies*, 26, 1891–1912.

NELSON, C. R. AND A. F. SIEGEL (1987): "Parsimonious modeling of yield curves," *Journal of business*, 473–489.

TOBIN, J. (1969): "A general equilibrium approach to monetary theory," *Journal of money, credit and banking*, 1, 15–29.

TOMA, M. (1992): "Interest Rate Controls: The United States in the 1940s," *The Journal of Economic History*, 52, 631–650.

VAYANOS, D. AND J.-L. VILA (2021): "A Preferred-Habitat Model of the Term Structure of Interest Rates," *Econometrica*, 89, 77–112.

VISSING-JORGENSEN, A. AND A. KRISHNAMURTHY (2011): "The effects of quantitative easing on interest rates: Channels and implications for policy," *Brookings Papers on Economic Activity*, 43, 215–287.

WRIGHT, J. H. (2012): "What does monetary policy do to long-term interest rates at the zero lower bound?" *The Economic Journal*, 122, F447–F466.